This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.
+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

[redacted]

The Branner Geological Library

LELAND·STANFORD·JVNIOR·VNIVERSITY

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 382

THE EFFECT OF OXYGEN IN COAL

BY

DAVID WHITE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

283353

CONTENTS.

	Page.
Introduction	5
Deoxygenation in the formation of coal	6
Initial controlling factors	6
Stages of formation	6
Deoxygenation	7
Oxygen and ash as impurities	8
Evidence of their nearly equal value	8
Calorimeter tests	8
Ultimate analyses	9
Arrangement of analyses	19
Fuels high in oxygen or ash	19
Fuels of lower ash and oxygen	20
Relation to calorific value	21
Curve platted from C : (O+ash) ratios and efficiencies	22
Determination of curve	22
Detailed study of a curve segment	22
Variations from the curve	23
Comparison with calculated thermal units	24
Forecast of fuel efficiency from ratios	24
Relations in moisture-free coals	25
Recalculation of analyses	25
Compensated calorific values	34
Value of moisture-free data	35
Relative negative value of ash and oxygen	36
Relative effect of the oxygen of moisture	37
Estimate of the empirical anticalorific value of oxygen	39
Negative value of oxygen and ash	39
Application of the curve	39
Fluctuation in effects of changes	40
Estimate applied to the analyses	40
Causes of variance from the curve	41
General statement	41
Causes not shown by ultimate analyses	41
Causes recognizable in analyses	42
Varying available hydrogen	43
Sulphur	44
Nitrogen	46
Anthracitization	46
Weathering	48
Quantitative relation of oxygen to coking	48
Supposed algal ingredients in coals	48
Source and chemical effects	48
Characteristics of algal coals	50
Possible connection with coking quality	50

Quantitative relation of oxygen to coking—Continued. Page.
Hydrogen-oxygen ratios of coking coals 51
Description of diagram in Plate III 51
Indications of ratio limits 52
Application to algal hypothesis 53
Coking of high fixed carbon coals 53
Volatile-carbon ratios 53
Consultation of efficiency errors 54
Hydrogen and oxygen losses in the progressive development of coal 54
Available hydrogen as index of coking coals 55
Hydrogen-oxygen ratio the best index 56
Status of algal hypothesis 56
Mixture of coals for coking 57
General observations on the tabulated coals 58
Range of the samples 58
Rank of peats and lignites 58
Explanation of high oxygen 59
Quantitative relation of volatile carbon and hydrogen 59
Loss of volatile matter 60
Relation of stage of coal formation to classification 60
Like analyses for coals of different origin 60
Distinct categories impossible 61
Comparison of types 61
Obliteration of distinctions as a result of regional metamorphism 62
Oxygenation and weathering of coals 63
Changes in low-grade coals 63
Efficiency losses in weathering 63
Losses shown by analyses and ratio-efficiency curve 64
Losses shown by H : O and VC : C ratios 65
Underground weathering 67
Losses by weathering in shipment 69
Summary 70
Partial bibliography 73
Index 75

ILLUSTRATIONS.

Page.
PLATE I. Ratio-efficiency curve of coals tabulated 22
II. Segment of ratio-efficiency curve 22
III. Diagram showing hydrogen-oxygen ratios of coals 52

THE EFFECT OF OXYGEN IN COAL.

By David White.

INTRODUCTION.

This paper is the result of a comparative study of ultimate coal analyses made and published by the United States Geological Survey. This study, at first casually undertaken to devise an acceptable classification of coals based on chemical analyses, was continued in connection with a microscopic examination of a number of the coals. The initial comparisons, made from a relatively small number of analyses, not only confirmed a previous conviction that the elimination of oxygen incident to the development of a coal is economically far more important than has been generally suspected, but also showed that oxygen is very nearly as harmful as ash in coal.

The immediate purposes of the present study were: (*a*) To determine more definitely, from a comparative examination of a large number of ultimate analyses, the relative importance of oxygen as an impurity in various coals; (*b*) to illustrate the transition between various grades of coal of similar origin—transition mainly due to progressive devolatilization, brought about more or less directly by dynamic influences; (*c*) to ascertain the relative proportions of oxygen, hydrogen, and carbon in coking coals, especially with reference to a theory tentatively framed to explain the coking quality; and (*d*) to forecast the probabilities of successfully treating a large number of coals so as to render them amenable, in a softened condition, to satisfactory study under the microscope.

Although the hypothesis as to coking quality finds but partial support in the chemical analyses, its consideration has led to a method of predicting from an analysis with a fair degree of certainty whether any given coal will coke by the ordinary process. The unbroken transition between coals originally similar but now classed in widely different groups, whether of the same age or of different ages, as a result of dynamochemical action, appears demonstrated by the analyses as well as by field observation. This subject will not be

specially discussed in this paper, though the tables offer forcible, if not convincing, evidence concerning it.

The great number of ultimate analyses published by the Survey, covering samples of coals of so many sorts collected throughout the wide range of American coal fields, furnishes an unrivaled wealth of analytical data concerning the fuels of the country; and the fact that all are made under one highly expert direction, and are standardized, renders them especially valuable for comparative study.

The discussion of chemical changes that have occurred in the coals and of the nature of the compounds now existing in them is left to the professional chemist, who is familiar with the great mass of literature concerning the chemistry of coals.

Acknowledgments are gratefully tendered to Messrs. M. R. Campbell and J. S. Burrows for placing at my disposal many of their recalculations of the analyses from the "as received" to the "air-dried" basis and thus greatly lightening the labors of computation; also to Mr. Burrows for annotations as to the coking qualities of the coals. Thanks are also due to Mr. Wirt Tassin, of the National Museum, for frequent and generous gifts of information and counsel.

DEOXYGENATION IN THE FORMATION OF COAL.

INITIAL CONTROLLING FACTORS.

The great variation in kinds and qualities of coal is due to differences, many of them of wide range, in the consecutive influence or operation of three controlling and indispensable factors; that is, to differences (1) in the kinds and sources of the original ingredient matter; (2) in the conditions of accumulation and deposition of this matter; and (3) in the phase and stage of progress of the coal-forming process—the transformation of the organic matter into coals of various grades. The comparative importance of each of these cooperative and mutually related factors varies from coal to coal, and it is necessary to bear in mind that they combine not only in complex but also in constantly changing phases and efficiencies, so that their products, though often similar, are never exactly the same. It is to the third of these factors that the following discussion for the most part relates.

STAGES OF FORMATION.

When the organic matter, chiefly of various vegetal types, accumulates under conditions favorable for the formation of coal, the process of conversion goes forward. In the ordinary course of events this process embraces two fundamentally important stages:

1. The putrefaction or fermentation stage, in which the action is essentially biochemical.

2. The stage of chemical and physical alteration, which is mainly induced and controlled by dynamic geologic influences, and in which the action may therefore, in contrast, be termed dynamochemical.

These two stages are practically consecutive, though slightly overlapping; and, on account of conditions that will readily be conceived and need not be discussed here,[a] the intensity and extent of the operation or progress of each stage varies greatly. The physical characters and qualities of the younger and less mature coals, including lignites and peats, are largely determined by the relative progress of the biochemical action, the most evident visible effect of which is the disintegration of the organic structures, usually accompanied by darkening of the color. On the other hand, the further progressive devolatilization, as well as the lithification, dehydration, and metamorphism of the coals, characterize the dynamochemical stage. The biochemical action, essentially the work of anaerobic bacteria, is, geologically speaking, relatively soon terminated, even when it progresses to a point just short of complete destruction of the original organism; the succeeding work, under the influence of geodynamic agencies, is still in progress, the ultimate goal being the practically complete devolatilization of the coal and its transformation into graphite.

DEOXYGENATION.

In all the chemical changes marking both stages in the conversion of organic débris into coal, the preeminently important result to man is elimination of oxygen. Economically this is the most essential incident of the process. From a beginning with over 40 per cent of oxygen, in the cellulose and lignose of the woody matter, which comprises so great a part of the organic substance actually entering into coal formation, to the present nearly devolatilized state of an anthracite, with less than 2.5 per cent of oxgyen, deoxygenation has progressed continuously, though at varying rates, in every unweathered coal. As the original oxygen is more and more nearly eliminated, the heat efficiency of the coal increases. In other words, with respect to their efficiency as fuels, oxygen is an original impurity in coals, which improve according to the extent of its removal. It will be shown later that the deleterious effect of oxygen in coals greatly exceeds the common conception of it, being nearly equal to that of the same weight in ash. The negative importance of oxygen seems to be little realized outside of the ranks of coal analysts.

[a] See Econ. Geology, vol. 3, 1908, p. 292.

OXYGEN AND ASH AS IMPURITIES.

EVIDENCE OF THEIR NEARLY EQUAL VALUE.

CALORIMETER TESTS.

At a conference held in Washington, March, 1907, for the purpose of discussing the classification of coals, I urged that a classification based on chemical composition, to be satisfactory for either technical or practical purposes, should give careful heed to the oxygen content, for the degree of deoxygenation would be found to be most intimately connected with the relative efficiency of the fuels. By using the limited number of ultimate analyses then made public by the fuel-testing plant of the United States Geological Survey as a basis of illustration, it was shown that, among coals of equal ash, the ascertained calorific values of the air-dried samples corresponded closely to the order of the ratios of the total carbon to the oxygen (C : O). The number of ultimate analyses showing approximately equal ash was, however, so small as to be inconclusive. I therefore attempted, by means of a critical comparison of all the analyses, to discover a coefficient for use in compensating for the highly variable ash content. From this study it was noted that, in general, so far as shown in the calorimeter, the deleterious effects of oxygen and of ash in the coals represented in the list were practically of very nearly equal importance. For example, the calorimeter tests seemed to show that two coals having the same carbon content, but with reverse proportions of ash and oxygen (one with 15 per cent ash and 4 per cent oxygen and the other with 4 per cent ash and 15 per cent oxygen) have nearly the same heat efficiency. In other words, oxygen and ash appear to be of nearly equal negative or anticalorific values.

The fact having been noted that the coals with constant ash arrange themselves as to efficiency largely in the order of the ratios of carbon to oxygen, it at once became evident, oxygen and ash being of equal negative calorific effect, (1) that coals with constant oxygen should also similarly rank not far from the order of their carbon-ash ratios; and (2) that the efficiencies of coals in which both oxygen and ash vary should correspond nearly equally well to the relative order of the ratios of the carbon to oxygen plus ash. Examination of a more extended series of analyses confirms the conclusions based on the original list.

In these comparative studies the contribution of the hydrogen of the coal to the heat value is assumed to be nearly constant; hence the hydrogen is ignored temporarily, as also are the sulphur and the nitrogen. The main purpose is to show that in a miscellaneous series of coals of all grades those with high oxygen content will, in general, have approximately the same calorific value as those with

equally high ash if the C: (O + ash) ratios are the same; or, in other words, that, taking coals as they run, oxygen and ash are, according to the calorimetric tests, to be regarded as equally undesirable.

ULTIMATE ANALYSES.

To illustrate somewhat graphically the approximate equality of the anticalorific values of these two great impurities in coal, while at the same time showing the relatively close correspondence of the calorific values to the sequence of the ratios C: (O + ash), Table 1 (pp. 11–18) has been compiled showing a series of over 300 ultimate analyses of air-dried samples of fuels. All these analyses were made in the laboratories of the United States Geological Survey.

As first compiled the table included all the ultimate coal analyses which, in December, 1907, had come to hand. By mere coincidence they numbered 250. Nearly 70 additional analyses of samples by the geologists working in the various coal areas have since been intercalated. These intercalations, many of which represent weathered material, have alphabetic designations affixed to the numbers, thus retaining the original series of numbers for the mined coals especially investigated by the Survey.

The air-dried coal samples, according to the later practice of the chemical laboratory, are those that, after pulverization, were dried in a special oven in a gentle current of air 10° to 20° above the temperature of the laboratory.[a] In the earlier laboratory work the samples were crushed fine, spread out on shallow trays, and dried in the air of the laboratory for twenty-four to ninety-six hours, or until the loss between two successive weighings (made twelve to twenty-four hours apart) was small, usually less than 1 per cent.[b]

All but one of the analyses will be found in Professional Paper 48, or in Bulletins 260, 261, 290, 316, or 332 of the United States Geological Survey. Most of the recalculations of the analyses and computations of ratios in this paper were done without the aid of the computing machine and are subject to correction. For original forms, including "as received" and "dry coal" recalculations, the reader is referred to the papers here mentioned.

It will be observed that the coals here listed represent most of the American coal fields. They come from 27 States and Territories. One is from Batan Island and one from Mexico. In age they range from basal Mississippian (Pocono) to Recent. The post-Paleozoic coals belong to the Kootenai (basal Cretaceous); Benton, Eagle, Mesaverde, and Laramie (Upper Cretaceous); "Upper Laramie," Fort Union, Bridger, and Gulf Coast Eocene; Pacific Coast Miocene;

[a] For description of this process see Bull. U. S. Geol. Survey No. 290, 1906, pp. 29–30.

[b] See Prof. Paper U. S. Geol. Survey No. 48, 1906, p. 177. For comparison of results see Bull. U. S. Geol. Survey No. 323, p. 8.

and Atlantic Coast post-Pleistocene. In kinds they embrace peats and xyloid and earthy lignites (brown coals), as well as subbituminous, bituminous (dry and coking), semibituminous, semianthracite, anthracite, and graphitic coals. In order not to omit any ultimate analysis of a coal investigated by the Survey, so far as they had come to hand up to the close of 1907, the semigraphite from Providence is also included. The graphitization of this highly metamorphic Carboniferous coal is so nearly complete that, although a coal from the genetic standpoint, it can not be regarded as a fuel, for it is practically incombustible unless chemically treated. It is used mainly for foundry facing. The lower-class coals are distinguished in accordance with the simple and very practical system recently proposed by M. R. Campbell.[a] This classification, based on weathering and salient physical characters, is briefly as follows:

Bituminous coals, except cannel and block (which are recognized by special well-known criteria), are more thoroughly jointed, and in weathering split generally in agreement with preexisting cleavage, the particles remaining prismatic even when very minute.

Subbituminous coals are black, generally less jointed, and have poor cleavage, which shows only in the larger blocks. On exposure to the atmosphere the lumps check irregularly, the resultant fragments, however small, being irregular in outline and having rough faces instead of cleavage planes. Weathering is characterized (very conspicuously in the longer exposed fragments) by separation of the coal in plates parallel to the bedding, this process continuing to invisible limits.

Lignites are distinguished from subbituminous coals only by their brown, instead of black, color and generally woody aspect. They are the "brown coals."

The higher grade coals are provisionally grouped as proposed by Prof. F. F. Grout.[b]

It will be noted that the samples analyzed are not always marketable coal; in many cases they represent fine coal, screenings, refuse, slack, dust (culm), waste and "bone." The low position of a number of the high-grade coals—for example, No. 30 (W. Va. 24) from the famous Pocahontas bed—is accounted for by the great amount of ash in the bony layer from which the sample was taken.

---

[a] Econ. Geology, vol. 3, 1908, p. 134. [b] Op. cit., vol. 2, 1907, p. 240.

TABLE 1.—*Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C : (O+ash) ratio of each coal.*

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C / O+ash.	Calories.	Moisture.	Fixed carbon.	Volatile matter.	Age.	Formation.	Remarks.
1	Mass. 1	Halifax	P.	1.40	0.58	5.55	40.78	30.95	20.74	0.79	4,055	13.60	18.72	46.94	Recent		
2	N. Dak. 1B	Lehigh	L.	.55	3.95	5.57	44.11	33.07	12.75	.96	4,321	24.82	29.85	32.58	Tertiary	Fort Union	Car sample.
2a	Mont. 3701	Near Miles	S.	.65	.66	4.51	48.01	28.17	18.00	1.04	[a]4,432	15.12	36.54	30.34	do	do	Country bank.
2b	Wyo. 3694	Labarge Range	S.	.85	.61	4.45	48.65	38.57	6.87	1.07	[b]4,468	10.88	40.15	39.15	Cretaceous	Montana	Prospect.
3	N. Dak. 3	Wilton	L.	1.39	1.32	5.88	47.45	35.08	8.88	1.08	4,498	26.64	27.92	36.56	Tertiary	Fort Union	Mine; car sample.
4	Ark. 10	Lester	L.	.91	.65	5.60	48.51	31.36	12.97	1.09	4,714	19.13	32.54	35.36	Eocene		Oil rock.
4a	Mont. 3816	Near Glendive	L.	.65	1.55	5.63	48.55	34.21	9.41	1.11	[a]4,522	24.11	15.80	50.68	Tertiary	Fort Union	Country bank.
5	N. Dak. 2B	Williston	L.	.88	.71	5.66	50.79	35.86	6.10	1.21	4,922	22.77	35.72	34.41	do	do	Car sample.
6	Fla. 1	Orlando	P.	2.56	.49	6.06	51.18	34.03	5.68	1.28	4,961	13.19	24.30	56.83	Recent		Briquetted.
7	Tex. 1	Crockett	L.	.95	1.04	5.57	52.06	25.53	14.85	1.29	5,199	13.40	29.00	42.75	Eocene		Mine; car sample.
8	N. Dak. 1	Lehigh	L.	.71	2.02	5.22	52.66	27.15	12.24	1.31	5,034	15.42	33.61	38.73	Tertiary	Fort Union	Do.
9	Wyo. 3	Aladdin	B.?	.72	6.86	5.03	49.59	20.60	17.20	1.31	5,108	12.58	34.82	35.39	Cretaceous	Montana	Do
9a	Wyo. 3892	Fall River	S.	1.40	2.85	4.70	52.58	23.72	14.75	1.36	[b]5,106	10.32	30.48	43.46	Tert.-Cret.?	Evanston	Surface sample.
10	Ind. T. 5	Lehigh	B.	1.22	4.06	4.18	52.39	12.40	25.75	1.37	5,201	5.74	37.05	31.46	Carboniferous	"Coal Meas."	Slack.
11	Cal. 1	Tesla	S.	.73	3.40	5.32	52.83	20.41	17.29	1.41	5,275	9.05	34.23	39.43	Tertiary		Mine; car sample.
12	Mo. 7C	Noringer	B.	.98	3.47	3.95	53.55	10.48	27.57	1.41	5,399	2.48	38.78	31.17	Carboniferous	"Coal Meas."	Slack.
12a	Wyo. 2326	Uinta County	S.	.88	4.78	4.86	52.53	19.60	17.35	1.42	5,261	7.21	36.95	37.96	Tert.-Cret.?	Evanston	Small mine.
13	N. Dak. 2	Williston	L.	.91	.63	5.61	55.16	30.98	6.71	1.46	5,273	16.73	39.49	37.10	Tertiary	Fort Union	Mine; car sample.
14	Ill. 2	O'Fallon	B.	.78	4.30	4.57	54.06	12.13	24.16	1.48	5,471	5.31	36.24	34.29	Carboniferous	"Coal Meas."	Slack.
15	Mo. 7A	Noringer	B.	1.01	3.46	4.65	54.30	14.23	22.35	1.48	5,503	7.41	38.12	32.12	do	do	Nut coal.
16	Mo. 3	Mendota	B.	.92	4.13	4.52	54.79	12.34	23.30	1.56	5,506	5.51	39.11	32.08	do	do	Slack.
17	N. Mex. 2	Gallup	S.	.98	1.30	5.05	56.71	16.74	19.22	1.57	5,668	8.13	37.83	34.82	Cretaceous	Mesaverde	Mine; car sample.
18	Wyo. 2	Cambria	B.	.80	4.17	4.54	55.29	12.94	22.26	1.57	5,758	2.73	37.40	37.61	do	Montana	Mine.
19	Tex. 2	Hoyt	L.	1.06	.71	5.28	57.31	25.83	9.81	1.60	5,502	10.66	40.11	39.42	Eocene		Mine; car sample.
20	Wyo. 2B	Cambria	B.	.85	4.22	4.59	55.84	12.72	21.77	1.62	5,815	4.64	35.35	38.24	Cretaceous	Montana	Mine.
21	Mexico		B.	1.02	.96	3.97	58.97	6.36	29.33	1.63	5,920	.91	47.69	22.07	Unknown		
22	Tex. 4	Hoyt	L.	.97	.70	5.06	58.83	24.48	9.96	1.71	5,682	9.76	42.77	37.51	Eocene		Mine; car sample.
23	Mo. 10	Bevier	B.	.97	4.28	4.05	57.25	9.69	23.76	1.71	5,857	1.77	43.97	30.50	Carboniferous	"Coal Meas."	Screenings.
24	Tex. 3	Olsen	L.	1.18	1.30	5.13	58.43	23.66	10.30	1.72	5,715	9.88	43.65	36.17			Mine; car sample.
25	Wyo. 1	Monarch	S.	1.09	.63	6.09	58.41	28.99	4.79	1.73	5,753	17.69	39.56	37.96	Tertiary	Fort Union	Do.
25a	Mont. 3512	Belt district	B.	.65	1.71	4.17	59.65	15.19	18.63	1.76	5,824	4.57	50.65	26.15	Cretaceous	Kootenai	Mine sample.
26	Ill. 7A	Collinsville	B.	.99	4.63	4.73	57.43	14.00	18.22	1.78	5,863	6.80	38.16	36.82	Carboniferous	"Coal Meas."	Slack.
27	Tenn. 11	Ozone	B.	1.13	.92	3.96	60.56	4.90	28.53	1.81	5,836	1.26	48.97	21.24	do	Pottsville	Do.
28	Mo. 7B	Noringer	B.	1.02	4.13	4.23	57.82	8.98	22.82	1.81	5,853	2.17	40.95	34.06	do	"Coal Meas."	Nut coal.
28a	Colo. 3856	Near Thompson's	B.	1.35	.60	4.86	60.49	13.23	19.47	1.85	6,029	4.14	43.75	32.64	Cretaceous	Mesaverde	Small mine.
29	Mont. 2	Fromburg	S.	1.14	.62	4.75	60.97	16.60	15.92	1.87	6,020	5.39	46.03	32.66	do	Eagle	Mine; car sample.
30	W. Va. 24	Gary	Sb.	.66	.55	3.33	62.36	3.97	28.77	1.90	6,002	.52	58.60	12.11	Carboniferous	Pottsville	"Bony" layer.
31	Mont. 1	Red Lodge	S.	1.36	.76	5.25	60.41	20.00	11.22	1.93	5,989	9.05	43.03	36.70	Tertiary	Fort Union	Mine; car sample.
31a	Colo. 3729	Carbonera	B.	1.30	.50	5.37	61.17	16.58	15.08	1.93	6,089	6.76	44.45	33.71	Cretaceous	Mesaverde	Mine sample.

[a] Coals more or less weathered.

[b] From shallow mine or country bank.

TABLE 1.—*Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C:(O+ash) ratio of each coal*—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C / O+ash	Calories.	Moisture.	Fixed carbon.	Volatile matter.	Age.	Formation.	Remarks.
32	Colo. 1	Lafayette	S.	1.22	.58	5.75	61.13	24.95	6.32	1.95	5,995	13.49	43.03	37.11	Cretaceous	Laramie	Mine; car sample.
33	Ill. 24A	Livingston	B.	.97	4.56	4.71	59.37	12.88	17.51	1.95	6,068	4.92	43.89	33.68	Carboniferous	"Coal Meas."	Screenings.
33a	N. Mex. 3811	West of Putnam	S.	1.51	1.92	5.50	60.32	20.61	10.14	1.96	5,994	8.86	43.13	37.87	Cretaceous	Mesaverde	Little depth.
34	Ind. 20	Brazil	B.	1.16	2.17	4.63	60.96	11.09	19.99	1.96	6,089	4.38	44.73	30.90	Carboniferous	"Coal Meas."	Screenings.
35	Ark. 9	Bonanza	Sb.	1.28	1.04	3.59	62.49	5.70	25.90	1.97	6,067	1.11	57.64	15.35	do	do	Slack.
36	Iowa 5	Chariton	B.	1.22	3.42	5.35	59.89	16.57	13.55	1.98	6,105	9.22	44.52	32.71	do	do	Run of mine.
37	Mont. 3	Bridger	S.	1.09	.56	4.87	62.32	17.34	13.82	2.00	6,126	5.63	47.15	33.40	Cretaceous	Eagle	Mine; car sample.
38	Ill. 27	Auburn	B.	1.01	4.50	4.93	59.88	14.38	15.30	2.01	6,135	6.67	42.02	36.01	Carboniferous	"Coal Meas."	Run of mine.
39	Ill. 4	Troy	B.	1.17	1.34	5.33	61.79	18.32	11.85	2.03	6,106	11.40	44.30	32.45	do	do	Lump.
39a	Wyo. 3699	Labarge Range	S.	1.09	1.14	5.39	62.05	24.56	5.77	2.04	[a]6,039	9.02	47.55	36.59	Cretaceous	Montana	Coal drift.
39b	Wyo. 3780	Northeast of Hanna	S.	1.73	2.41	5.73	60.53	23.55	6.05	2.04	[b]6,040	10.12	48.13	35.70	(?)	"Upper Laramie."	Exposed.
40	Ind. 3	Boonville	B.	1.18	5.24	4.83	59.58	12.09	17.08	2.04	6,090	5.12	42.92	34.88	Carboniferous	"Coal Meas."	Small size.
41	Wyo. 4	Hanna	S.	.90	.29	5.42	62.68	23.23	7.48	2.04	6,116	9.21	42.04	45.27	Tertiary	Fort Union	Mine; car sample.
42	Ill. 8	Paisley	B.	1.08	4.68	5.25	59.88	16.01	13.10	2.06	6,110	9.21	41.78	35.31	Carboniferous	"Coal Meas."	
43	Mo. 1	Sprague	B.	.99	5.53	4.64	60.00	8.46	20.38	2.08	6,191	3.50	40.77	35.35	do	do	
44	Ill. 6	Coffeen	B.	1.23	4.45	4.88	60.51	14.20	14.73	2.09	6,199	5.13	47.46	32.68	do	do	Run of mine.
44a	Wyo. 3693	Labarge Range	S.	1.03	2.10	5.74	61.76	25.96	3.41	2.10	[a]6,057	10.78	43.94	40.46	Cretaceous	Montana	Prospect.
44b	Mont. 3515	Belt district	B.	.69	3.80	4.02	62.51	9.16	19.82	2.11	6,094	1.93	51.44	26.81	do	Kootenai	Country bank.
45	Ill. 23A	Donkville	B.	1.04	4.58	4.55	60.93	10.94	17.96	2.11	6,180	2.86	43.14	36.04	Carboniferous	"Coal Meas."	Lump.
46	Wash. 1	Renton	S.	1.30	.68	4.91	63.28	16.92	12.91	2.12	6,182	5.98	45.96	35.15	Eocene		Pea coal; car sample.
46a	Colo. 4050	Near Glenwood Springs.	B.	1.58	.98	5.04	62.74	19.71	9.95	2.12	6,226	7.05	47.60	35.40	Cretaceous	Mesaverde	Mine sample.
47	Ill. 21B	Troy	B.	1.24	1.17	5.14	62.84	17.26	12.35	2.12	6,278	8.52	46.95	32.18	Carboniferous	"Coal Meas."	
48	Iowa 2	Hamilton	B.	1.46	5.20	4.84	60.36	11.15	16.99	2.14	6,212	4.25	41.75	37.02	do	do	Run of mine.
49	Ill. 7B	Collinsville	B.	1.03	4.69	5.14	60.71	14.77	13.66	2.14	6,229	7.60	41.19	37.55	do	do	
50	Wash. 1B	Renton	S.	1.29	.80	5.16	63.35	16.82	12.58	2.15	6,273	5.20	45.68	36.54	Eocene		Run of mine; car sample.
51	Ind. 1	Mildred	B.	1.22	2.58	5.20	62.20	14.99	13.81	2.16	6,336	8.66	42.67	39.86	Carboniferous	"Coal Meas."	Run of mine.
51a	Philip	Batan Island	S.	1.33	1.36	5.55	62.91	23.29	5.56	2.17	[c]6,101	7.06	43.44	43.94	Miocene?		Probably oxidized.
52	Iowa 4	Centerville	B.	.94	4.46	5.31	61.25	16.56	11.48	2.18	6,237	10.03	41.22	37.27	Carboniferous	"Coal Meas."	Lump.
52a	N. Mex. 3952	Near Blackrock	B.	1.03	1.54	5.45	63.00	12.36	16.62	2.18	6,500	4.01	40.22	39.12	Cretaceous	Mancos	Mine sample (?).
52b	Wyo. 2325	Almy	S.	1.23	.22	4.97	64.28	21.56	7.73	2.19	6,220	7.73	44.52	39.45	Tert.-Cret.?	Evanston	Mine.
52c	Colo. 3463	Lay	B.	1.16	1.05	5.50	63.43	22.37	6.49	2.19	6,198	9.87	46.97	36.67	Cretaceous	Mesaverde	Prospect.
53	Ill. 25B	Germantown	B.	1.12	5.06	5.05	60.96	13.57	14.24	2.19	6,337	5.79	43.18	37.79	Carboniferous	"Coal Meas."	Lump.
53a	Wyo. 3917	Near Fort Steele	S.	1.56	.85	5.16	63.57	25.05	3.80	2.20	6,310	8.70	48.44	39.05	Cretaceous	Lewis	Shaft.
54	Ill. 9C	Staunton	B.	.95	4.39	4.31	62.23	10.41	17.71	2.21	6,273	2.25	47.09	32.95	Carboniferous	"Coal Meas."	
55	Ill. 22A	Maryville	B.	1.06	5.68	4.83	60.94	13.66	13.83	2.21	6,267	6.39	41.89	37.89	do	do	Lump.
55a	Wyo. 3698	Labarge Range	S.	1.08	.84	5.68	63.81	25.75	2.84	2.23	[a]6,258	10.22	45.98	39.47	Cretaceous	Montana	Drift.

56	Wyo. 4B	Hanna	S.	.88	.27	6.18	64.01	21.62	7.04	2.23	6,183	8.94	42.70	41.32	Tertiary	Fort Union	Mine; car sample.
57	Ill. 29B	Livingston	B.	.85	4.68	5.11	61.69	14.62	13.05	2.23	6,302	7.14	44.09	35.72	Carboniferous.	"Coal Meas."	Run of mine.
57a	Wyo. 3605	Hanna	S.	1.29	.50	5.41	64.07	21.58	7.14	2.23	6,420	8.07	42.85	41.93	Tertiary	Fort Union	Top bench No. 1; mine sample.
58	Ill. 6B	Coffeen	B.	1.10	4.67	4.69	61.96	12.15	15.43	2.24	6,229	4.17	47.77	32.63	Carboniferous.	"Coal Meas."	Run of mine.
59	Ill. 29	Livingston	B.	1.08	4.71	4.92	61.67	14.07	13.55	2.24	6,393	5.58	45.14	35.73	do	do	
60	Iowa 1	Laddsdale	B.	.97	5.20	4.61	61.80	10.90	16.52	2.25	6,329	5.21	46.51	31.76	do	do	Lump.
61	Ill. 1	O'Fallon	B.	1.07	4.25	5.09	62.01	13.86	13.72	2.25	6,360	6.28	41.08	38.92	do	do	Screened.
62	Ill. 15	Centralia	B.	1.09	4.04	4.99	62.25	13.82	13.81	2.25	6,356	6.00	43.91	36.28	do	do	Coarse coal.
62a	Utah 4013	Near Sunnyside	B.	1.30	.47	4.71	64.88	20.11	8.53	2.26	6,293	5.12	53.21	33.14	Cretaceous	Mesaverde	From prospect.
63	Iowa 3	Altoona	B.	.93	6.83	4.93	60.62	11.16	15.53	2.27	6,309	4.52	38.99	40.96	Carboniferous.	"Coal Meas."	Lump.
64	N. Mex. 1	Gallup	S.	1.05	.64	5.73	64.34	21.14	7.10	2.28	6,353	10.86	46.90	35.14	Cretaceous	Mesaverde	Mine; car sample.
65	Kans. 2B	Yale	B.	1.11	5.03	4.26	62.65	5.13	21.82	2.32	6,329	1.51	48.42	28.25	Carboniferous.	"Coal Meas."	Run of mine.
66	Ind. 14	Seelyville	B.	.97	5.34	4.99	62.05	11.90	14.75	2.33	6,430	4.34	42.64	38.27	do	do	Do.
66a	Colo. 3498	Meeker	B.	1.26	.76	5.20	64.95	20.41	7.42	2.33	6,446	7.18	46.50	38.90	Cretaceous	Mesaverde	Mine sample.
67	Ind. 13	Terre Haute	B.	.87	3.37	5.25	63.39	14.31	12.81	2.34	6,414	7.62	42.02	37.55	Carboniferous.	"Coal Meas."	Run of mine.
68	Ind. 4	Star City	B.	1.24	2.59	4.66	64.10	11.36	16.05	2.34	6,426	3.58	47.41	32.96	do	do	Sampled.
69	Ill. 30	Shiloh station	B.	1.03	4.80	4.92	62.60	12.20	14.45	2.35	6,510	3.27	43.18	39.10	do	do	Coal No. 6.
70	Ill. 21	Troy	B.	1.22	1.55	4.94	64.76	15.34	12.20	2.35	6,514	5.74	47.17	34.89	do	do	Lump.
71	Ill. 22B	Maryville	B.	1.00	4.90	4.52	62.99	10.23	16.36	2.36	6,376	2.06	44.81	36.77	do	do	Screenings.
72	Ind. T. 4	Lehigh	B.	1.38	4.02	4.84	63.21	13.15	13.40	2.38	6,327	4.91	43.90	37.79	do	do	Lump.
72a	Colo. 3545	Book Cliffs district	B.	1.47	.66	5.58	65.05	20.96	6.28	2.38	[b]6,312	10.00	50.98	32.74	Cretaceous	Mesaverde	Prospect.
73	Ill. 31	Worden	B.	1.14	4.05	4.83	63.47	11.84	14.67	2.39	6,394	3.77	45.94	35.62	Carboniferous.	"Coal Meas."	Screenings.
73a	Colo. 3490	Book Cliff field	B.	1.13	.89	5.13	65.51	16.92	10.42	2.39	6,532	6.17	47.13	36.28	Cretaceous	Mesaverde	Mine sample.
73b	Mont. 4115	Stockett district	B.	.92	2.43	4.33	65.17	12.66	14.49	2.40	6,348	3.70	52.68	29.13	do	Kootenal	Do.
73c	Wyo. 2283	Mammoth Holl	S.	1.03	.58	5.24	65.76	23.96	3.43	2.40	6,385	7.57	47.20	40.49	do	Montana	Mine; shallow.
74	Ind. 2	Boonville	B.	1.25	4.60	5.11	62.97	12.56	13.51	2.41	6,410	6.24	42.76	37.49	Carboniferous.	"Coal Meas."	Run of mine.
75	Ind. 17	Bicknell	B.	.94	3.85	5.03	63.70	14.87	11.61	2.41	6,446	7.36	46.80	34.23	do	do	Do.
75a	Colo. 3462	Lay	B.	1.22	1.14	5.53	65.33	20.41	6.37	2.44	[b]6,419	8.66	47.29	37.68	Cretaceous	Mesaverde	Outcrop.
75b	Colo. 3704	Axial	B.	1.40	.54	5.24	66.12	21.92	4.78	2.48	6,534	8.91	49.22	37.09	do	do	Mine sample.
76	Ill. 14	Springfield	B.	1.19	4.52	5.00	63.85	12.64	12.80	2.50	6,496	5.13	44.31	37.70	Carboniferous.	"Coal Meas."	Lump.
77	Ohio 3	Shawnee	B.	1.28	1.88	5.05	65.62	14.12	12.05	2.51	6,519	6.24	46.68	35.03	do	do	Sample.
78	Ill. 12	Bush	B.	1.14	3.61	4.86	64.85	12.11	13.43	2.54	6,548	4.77	48.34	33.46	do	do	Run of mine.
79	Kans. 2	Yale	B.	.94	6.40	4.56	63.14	6.69	18.27	2.54	6,600	2.23	47.63	31.87	do	do	Do.
80	Ind. 6	Hymera	B.	1.19	4.63	5.15	64.22	11.50	13.31	2.58	6,555	5.91	42.71	38.07	do	do	Do.
81	Ill. 9A	Staunton	B.	1.04	4.43	5.18	64.49	13.06	11.80	2.59	6,538	4.99	43.99	39.22	do	do	Do.
81a	Ariz. 4112	Near St. Michaels	B.	1.28	.42	5.75	66.81	21.69	4.05	2.59	6,723	9.89	46.95	39.07	Cretaceous	Mesaverde	
82	Ill. 26	Lincoln	B.	1.21	4.02	4.75	65.02	11.15	13.85	2.60	6,579	3.41	45.62	37.12	Carboniferous.	"Coal Meas."	Do.
83	Wyo. 6	Kemmerer	S.	1.10	.55	5.81	66.95	22.07	3.52	2.61	[d]6,456	8.68	46.49	41.31	Cretaceous	Montana	Run of mine; car sample.
84	Ill. 19E	Ziegler	B.	1.53	.54	4.54	67.48	14.99	10.92	2.61	6,625	5.27	52.58	31.23	Carboniferous.	"Coal Meas."	Screened.
84a	Colo. 3703	Axial	B.	1.12	.60	5.20	67.42	22.64	3.02	2.62	6,654	8.67	49.99	38.32	Cretaceous	Mesaverde	Old drift sample.
85	Ala. 2B	Carbon Hill	B.	1.52	1.14	4.46	67.35	10.69	14.84	2.63	6,660	2.29	51.64	31.23	Carboniferous.	Pottsville	Run of mine.
86	N. Mex. 3A	Van Houten	B.	1.25	.74	4.83	67.54	8.63	17.01	2.63	6,742	1.48	48.80	32.71	Cretaceous	Montana	Mine.
87	Ind. 16	Linton	B.	1.13	4.50	5.02	64.82	12.04	12.49	2.64	6,623	4.68	44.24	38.59	Carboniferous.	"Coal Meas."	Run of mine.
88	Kans. 6	Jewett	B.	1.14	4.00	4.54	65.65	7.75	16.92	2.66	6,663	2.09	49.03	31.96	do	do	Lump.
89	Tenn. 9B	Coalmont	B.	1.26	.78	4.72	67.76	6.01	19.47	2.66	6,693	1.03	52.89	26.61	do	Pottsville	Slack.
90	Mo. 5	Higbee	B.	1.02	5.68	4.69	64.52	8.72	15.37	2.67	6,614	1.71	44.95	37.97	do	"Coal Meas."	Run of mine.
91	Ind. 12	Hartwell	B.	1.25	4.13	5.01	65.28	11.88	12.45	2.68	6,688	4.45	45.68	37.42	do	do	Do.
92	Ohio 2	Superior	B.	1.25	4.17	5.17	65.14	12.51	11.76	2.68	6,625	5.61	45.44	37.19	do	do	Do

[a] From shallow mine or country bank. [b] Coals more or less weathered. [c] Sample probably deteriorated. [d] Car sample.

TABLE 1.—*Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C: (O+ash) ratio of each coal*—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C / O+ash	Calories.	Moisture.	Fixed carbon.	Volatile matter.	Age.	Formation.	Remarks.
93	N. Mex. 3B	Van Houten	B.	1.22	.86	4.60	68.00	8.91	16.41	2.68	6,823	1.40	48.98	33.21	Cretaceous	Montana	Mine.
94	Ill. 23B	Donkville	B.	1.03	4.98	4.91	65.10	10.95	13.03	2.71	6,598	2.23	45.93	38.81	Carboniferous	"Coal Meas."	Slack.
95	Ill. 19C	Ziegler	B.	1.49	.54	5.10	67.91	13.53	11.43	2.72	6,596	6.01	52.23	30.33	do	do	Run of mine.
96	Ill. 24A	New Baden	B.	1.10	5.33	4.94	64.86	12.20	11.57	2.72	6,575	4.36	47.43	36.64	do	do	Screenings.
97	Ill. 3	Marion	B.	1.43	1.77	4.92	67.30	12.99	11.59	2.74	6,724	5.96	52.16	30.29	do	do	Run of mine; No. 6.
98	Ind. 5	Hymera	B.	1.16	4.60	5.07	65.44	12.01	11.72	2.75	6,700	5.21	44.65	38.42	do	do	Run of mine.
99	Ill. 9B	Staunton	B.	1.09	4.40	5.14	65.57	12.32	11.48	2.75	6,717	4.03	44.18	40.31	do	do	Lump.
100	N. Mex. 3C	Van Houten	B.	1.20	.65	4.75	68.66	9.00	15.74	2.77	6,855	1.37	49.23	33.66	Cretaceous	Montana	Mine.
101	Ind. 11	Dugger	B.	1.44	1.47	5.22	67.63	15.76	8.48	2.79	6,806	8.49	48.16	34.87	Carboniferous	"Coal Meas."	Lump.
101a	Colo. 3550	Book Cliffs field	B.	1.26	.63	5.19	68.46	13.25	11.21	2.79	6,757	4.30	47.53	33.32	Cretaceous	Mesaverde	Mine sample.
102	Ind. 9	Maxville	B.	1.12	3.56	5.19	66.48	12.46	11.20	2.81	6,714	5.24	45.73	37.83	Carboniferous	"Coal Meas."	Lump.
103	Ind. 18B	Winston	B.	1.18	1.49	5.50	67.95	16.80	7.08	2.84	6,881	8.92	48.57	35.43	do	do	Do.
104	Ill. 34B	Harrisburg	B.	1.38	2.96	4.69	67.29	10.95	12.73	2.84	6,883	2.92	51.25	33.10	do	do	Run of mine.
105	Ohio 1	Wellston	B.	1.17	4.85	5.12	65.70	10.59	12.57	2.84	6,727	2.96	44.18	40.29	do	do	Do.
106	Ill. 19	Ziegler	B.	1.48	.57	4.85	69.05	14.23	9.82	2.86	6,697	6.39	54.46	29.33	do	do	Sized coal.
107	Ind. 9B	Maxville	B.	1.19	3.53	5.14	66.79	11.30	12.05	2.86	6,811	3.17	45.81	38.97	do	do	Run of mine.
108	Ky. 4	Wheatcroft	B.	1.28	4.67	4.53	66.50	8.43	14.59	2.88	6,830	2.54	46.79	36.08	do	do	Do.
109	Ohio 9B	Clarion	B.	1.12	3.55	4.80	67.31	10.58	12.64	2.89	6,805	2.65	45.65	39.06	do	do	Slack.
110	Ill. 10	West Frankfort	B.	1.46	1.56	4.88	68.56	11.25	12.29	2.89	6,866	2.79	50.57	34.35	do	do	Do.
110a	Wyo. 3891	McDougals Mountain.	B.	1.38	.33	5.31	69.07	18.99	4.92	2.89	6,879	6.50	48.42	39.95	Cretaceous	Benton	Prospect; new.
111	Ky. 3	Barnsley	B.	1.43	3.60	5.27	66.75	12.66	10.29	2.92	6,829	5.85	46.96	36.90	Carboniferous	"Coal Meas."	Run of mine.
112	Ill. 12B	Bush	B.	1.02	2.60	4.80	68.30	11.74	11.54	2.93	6,756	3.97	51.43	33.06	do	do	Do.
112a	Wyo. 3509	Fort Steele	B.	1.79	.88	5.17	68.93	17.24	5.99	2.96	6,759	5.72	49.76	38.53	Cretaceous	Mesaverde	Mine.
113	Mo. 6	Huntsville	B.	1.08	6.34	4.74	65.71	8.85	13.28	2.96	6,785	2.49	45.44	38.79	Carboniferous	"Coal Meas."	Lump.
114	Ala. 2	Carbon Hill	B.	1.55	1.02	4.79	69.24	10.87	12.53	2.96	6,916	2.58	51.74	33.15	do	Pottsville	Sized.
115	Ind. T. 8	(?)	B.	1.64	1.93	4.67	68.65	8.86	14.25	2.97	6,837	2.29	50.21	33.25	do	"Coal Meas."	Car sample.
116	Ill. 12C	Bush	B.	1.19	2.65	4.83	68.36	11.02	11.95	2.97	6,862	3.32	51.70	33.03	do	do	Run of mine.
117	Ind. 8	Terre Haute	B.	1.13	3.90	5.21	67.17	11.47	11.12	2.97	6,848	5.19	45.76	37.93	do	do	Lump; deep coal.
118	N. Mex. 4B	Brilliant	B.	1.53	.62	4.97	69.48	8.62	14.78	2.97	6,927	1.40	49.02	34.80	Cretaceous	Montana	Screenings.
119	Ill. 11B	Carterville	B.	1.37	2.62	4.88	68.25	10.50	12.38	2.99	6,901	3.25	51.19	33.18	Carboniferous	"Coal Meas."	Mixed.
120	Ill. 18	La Salle	B.	1.09	4.28	5.37	66.91	12.61	9.74	2.99	6,914	4.36	45.63	40.27	do	do	Lump.
121	Ala. 5	Lehigh	B.	1.33	1.46	4.40	69.64	6.35	16.82	3.00	6,920	1.24	55.74	26.20	do	Pottsville	Run of mine.
122	Ill. 13	Benton	B.	1.55	1.62	4.90	69.00	11.94	10.99	3.00	6,829	3.89	51.94	33.18	do	"Coal Meas."	Egg coal.
123	Ark. 1B	Huntington	Sb.	1.46	1.14	3.86	70.25	4.03	19.26	3.01	6,770	.85	63.64	16.25	do	do	Slack.
124	Ill. 28C	Herrin	B.	1.25	1.36	4.88	69.54	12.68	10.29	3.02	6,849	4.93	54.11	30.77	do	do	Lump.
125	Ind. T. 2B	Hartshorne	B.	1.72	1.88	4.51	69.15	7.71	15.03	3.04	6,915	1.44	49.49	34.04	do	do	Slack.
126	N. Mex. 4A	Brilliant	B.	1.53	.62	5.03	69.86	9.19	13.77	3.04	7,034	1.71	49.25	35.23	Cretaceous	Montana	Mine.
127	Ill. 12D	Bush	B.	1.22	2.70	4.75	68.81	11.54	10.98	3.05	6,910	2.97	53.54	32.51	Carboniferous	"Coal Meas."	

128	Wash. 2	Roslyn	B.	1.26	.38	5.08	70.26	10.60	12.42	3.05	7,084	1.88	48.73	36.97	Eocene			Do.
129	Ky. 7	Central City	B.	1.32	2.71	5.06	67.80	12.34	9.77	3.06	6,863	5.64	48.26	36.33	Carboniferous.	"Coal Meas."		Lump.
130	Ky. 2	Earlington	B.	1.25	3.72	5.33	67.64	12.18	9.38	3.06	6,966	5.36	46.27	38.99	do	do		Coarse coal.
131	Ohio 11	Flushing	B.	1.19	4.39	4.71	67.72	8.84	13.15	3.08	6,937	1.87	48.35	36.63	do	do		Lump.
132	Ind. 18A	Winslow	B.	1.38	1.69	5.48	69.08	15.17	7.20	3.08	6,898	8.29	48.28	36.23	do	do		Slack.
133	Ky. 9A	McHenry	B.	1.24	3.25	5.41	68.01	12.80	9.29	3.08	6,953	5.39	49.05	36.27	do	do		Nut.
134	Ala. 3	Garnsey	B.	1.15	.56	4.47	70.84	8.45	14.53	3.08	7,007	1.54	54.11	29.82	do	Pottsville		Run of mine.
134a	Colo. 3541	Book Cliffs field	B.	1.58	.87	5.14	69.83	16.47	6.11	3.09	6,978	5.63	51.49	36.77	Cretaceous	Mesaverde		Mine sample.
135	Ky. 9B	McHenry	B.	1.39	3.10	5.07	68.35	11.59	10.50	3.09	6,985	3.91	51.49	34.10	Carboniferous.	"Coal Meas."		Run of mine.
135a	Ill. 19B	Ziegler	B.	1.56	.64	4.51	70.55	13.11	9.63	3.10	6,897	3.87	55.19	31.31	do	do		Lump No. 6.
136	Ind. 15	Linton	B.	1.56	1.00	5.11	69.89	13.47	8.97	3.11	6,979	4.93	50.82	35.28	do	do		Run of mine.
136a	Colo. 3640	Book Cliffs field	B.	1.20	.49	5.38	70.32	16.87	5.74	3.11	6,908	5.21	55.69	33.36	Cretaceous	Mesaverde		Shallow; mine sample.
137	Ind. T. 3	Edwards	B.	1.50	3.67	4.85	68.18	10.52	11.28	3.12	6,927	3.45	47.82	37.45	Carboniferous.	"Coal Meas."		Run of mine.
138	Kans. 4	Atchison	B.	1.07	8.33	5.04	65.02	7.91	12.63	3.16	6,854	3.57	46.80	37.00	do	do		Lump.
139	Ill. 16	Herrin	B.	1.56	1.19	4.94	70.14	12.17	10.00	3.16	6,921	4.61	54.05	31.35	do	do		Do.
140	Va. 5A	Blacksburg	Sa.	.69	.66	3.60	72.23	4.02	18.80	3.16	6,929	.73	69.92	10.55	do	Pocono		
141	N. Mex. 5	Blossburg	B.	1.19	.70	4.79	70.95	7.59	14.78	3.17	7,065	1.34	51.58	32.30	Cretaceous	Montana		Mine.
142	Ind. 7	Littles	B.	1.25	3.88	5.40	67.99	11.93	9.55	3.17	6,920	5.50	44.99	39.96	Carboniferous.	"Coal Meas."		Lump.
143	Kans. 1	Fleming	B.	1.09	4.34	4.91	68.22	8.30	13.14	3.18	6,891	3.74	50.01	33.11	do	do		
144	Wyo. 5	Rock Springs	S.	1.52	.86	5.37	70.30	18.32	3.63	3.20	6,955	6.00	51.68	38.69	Cretaceous	Montana		Mine; car sample.
145	Ill. 11	Carterville	B.	1.39	2.07	4.84	69.91	10.64	11.15	3.21	6,978	3.11	52.71	33.03	Carboniferous.	"Coal Meas."		
146	Ind. T. 1	Henryetta	B.	1.29	1.99	5.14	69.85	11.38	10.35	3.21	7,011	3.87	50.05	35.73	do	do		
146a	Colo. 3946	Rifle Creek	B.	1.63	.71	5.32	70.39	16.47	5.48	3.21	7,075	4.24	53.04	37.24	Cretaceous	Mesaverde		Mine sample.
146b	Colo. 3586	Book Cliffs field	B.	1.63	1.31	5.33	70.00	15.34	6.39	3.22	7,024	4.84	50.49	38.28	do	do		Prospect.
146c	Wyo. 4302	Willow Creek	B.	1.55	.64	4.65	71.09	15.74	6.33	3.22	6,911	4.51	54.85	34.20	do	Benton		Do.
147	Ill. 19B	Ziegler	B.	1.48	.96	4.96	70.70	11.98	9.92	3.23	6,877	5.42	53.03	31.63	Carboniferous.	"Coal Meas."		Lump.
147a	Colo. 3943	Rifle Creek	B.	1.60	1.14	5.36	70.20	15.63	6.07	3.23	7,072	4.31	51.93	37.69	Cretaceous	Mesaverde		Mine sample.
147b	Cal. 3773	Stone Canyon	B.	1.19	4.26	6.18	67.50	14.50	6.37	3.24	7,086	4.86	41.03	47.74	Miocene			Do.
148	Ohio 7	Danford	B.	1.23	3.21	5.14	69.19	10.40	10.83	3.26	6,947	4.16	50.17	34.84	Carboniferous.	"Coal Meas."		
149	Ind. 7B	Littles	B.	1.24	4.14	5.11	68.94	10.34	10.23	3.34	7,020	2.76	46.55	40.46	do	do		Screenings.
149a	Colo. 3546	Book Cliffs field	B.	1.60	.74	5.38	71.03	15.16	6.09	3.34	7,069	5.49	54.10	34.32	Cretaceous	Mesaverde		Deep prospect.
150	Tenn. 6	Waldencia	B.	1.01	.80	4.66	72.14	6.53	14.86	3.37	7,159	1.02	55.69	28.43	Carboniferous.	Pottsville		Run of mine.
151	Tenn. 9A	Coalmont	B.	1.32	.96	4.64	71.84	6.78	14.46	3.38	7,135	1.36	56.22	27.96	do	do		Lump.
152	R. I. 1	Providence	G.	.17	.07	.69	76.63	2.99	19.45	3.41	6,229	.42	75.11	5.02	do	"Coal Meas."		Not a fuel.
153	Ind. 10	Rosedale	B.	1.26	4.17	5.40	69.07	10.77	9.33	3.43	7,113	2.85	45.07	42.75	do	do		Lump.
154	Ohio 8	Dixie	B.	1.35	2.97	5.21	70.18	11.52	8.76	3.46	7,055	3.19	48.26	39.79	do	do		Run of mine.
154a	Wyo. 3480	Fort Steele	B. ?	1.79	.95	5.56	71.24	16.73	3.71	3.48	[a]6,951	5.45	52.89	37.95	Cretaceous	Mesaverde		Weathered in mine.
155	Tenn. 1	Fork Ridge	B.	1.65	1.63	4.95	71.36	8.92	11.49	3.48	7,199	1.87	52.71	33.93	Carboniferous.	Pottsville		Run of mine.
156	Pa. 13	Creighton	B.	1.23	2.19	5.02	71.25	6.96	13.35	3.50	7,221	1.27	51.89	33.49	do	"Coal Meas."		Do.
157	Tenn. 8B	Clifty	B.	1.25	4.84	4.55	69.59	5.36	14.41	3.52	7,096	1.14	50.87	33.58	do	Pottsville		Do.
158	Tenn. 7A	Wilder	B.	1.29	3.32	4.92	70.46	6.94	13.07	3.52	7,122	1.36	50.06	35.51	do	do		Lump.
159	Ala. 1	Horse Creek	B.	1.66	.73	4.96	72.16	7.85	12.64	3.52	7,199	1.56	53.71	32.10	do	do		Sized.
160	Ind. T. 2	Hartshorne	B.	1.72	1.56	5.00	71.49	8.91	11.32	3.53	7,205	1.70	49.79	37.19	do	"Coal Meas."		Run of mine.
160a	Colo. 3936	Newcastle	B.	1.40	.44	5.07	72.65	13.49	6.95	3.55	7,243	2.81	53.25	36.99	Cretaceous	Mesaverde		Mine sample.
161	Ga. 1	Menlo	Sb.	1.13	1.31	4.09	72.92	5.58	14.97	3.55	7,341	.62	68.01	16.40	Carboniferous.	Pottsville		Lump.
161a	Wyo. 4323	Greys	B.	1.48	.28	5.14	72.97	18.45	1.68	3.62	7,358	4.20	56.36	37.60	Cretaceous	Benton		Prospect.
162	Va. 5B	Blacksburg	Sa.	.74	.70	3.85	74.33	2.91	17.47	3.65	7,112	.45	71.00	11.08	Carboniferous.	Pocono		
163	Pa. 3	Scranton	A.	.80	.77	2.81	75.21	4.08	16.33	3.68	6,929	2.08	74.32	7.27	do	"Coal Meas."		Waste culm.

[a] Coals more or less weathered.

TABLE 1.—*Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C:(O+ash) ratio of each coal*—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C/(O+ash)	Calories.	Moisture.	Fixed carbon.	Volatile matter.	Age.	Formation.	Remarks.
32	Colo. 1	Lafayette	S.	1.22	.58	5.75	61.13	24.95	6.32	1.95	5,995	13.49	43.03	37.11	Cretaceous	Laramie	Mine; car sample.
33	Ill. 24A	Livingston	B.	.97	4.56	4.71	59.37	12.88	17.51	1.95	6,068	4.92	43.89	33.68	Carboniferous	"Coal Meas."	Screenings.
33a	N. Mex. 3811	West of Putnam	S.	1.51	1.92	5.50	60.32	20.61	10.14	1.96	5,994	8.86	43.13	37.87	Cretaceous	Mesaverde	Little depth.
34	Ind. 20	Brazil	B.	1.16	2.17	4.63	60.96	11.09	19.99	1.96	6,089	4.38	44.73	30.90	Carboniferous	"Coal Meas."	Screenings.
35	Ark. 9	Bonanza	Sb.	1.28	1.04	3.59	62.49	5.70	25.90	1.97	6,067	1.11	57.64	15.35	do	do	Slack.
36	Iowa 5	Chariton	B.	1.22	3.42	5.35	59.89	16.57	13.55	1.98	6,105	9.22	44.52	32.71	do	do	Run of mine.
37	Mont. 3	Bridger	S.	1.09	.56	4.87	62.32	17.34	13.82	2.00	6,126	5.63	47.15	33.40	Cretaceous	Eagle	Mine; car sample.
38	Ill. 27	Auburn	B.	1.01	4.50	4.93	59.88	14.38	15.30	2.01	6,135	6.67	42.02	36.01	Carboniferous	"Coal Meas."	Run of mine.
39	Ill. 4	Troy	B.	1.17	1.34	5.33	61.79	18.32	11.85	2.03	6,106	11.40	44.30	32.45	do	do	Lump.
39a	Wyo. 3699	Labarge Range	S.	1.09	1.14	5.39	62.05	24.56	5.77	2.04	a6,039	9.02	47.55	36.59	Cretaceous	Montana	Coal drift.
39b	Wyo. 3780	Northeast of Hanna	S.	1.73	2.41	5.73	60.53	23.55	6.05	2.04	a6,040	10.12	48.13	35.70	(?)	"Upper Laramie."	Exposed.
40	Ind. 3	Boonville	B.	1.18	5.24	4.83	59.58	12.09	17.08	2.04	6,090	5.12	42.92	34.88	Carboniferous	"Coal Meas."	Small size.
41	Wyo. 4	Hanna	S.	.90	.29	5.42	62.68	23.23	7.48	2.04	6,116	9.21	42.04	45.27	Tertiary	Fort Union	Mine; car sample.
42	Ill. 8	Paisley	B.	1.08	4.68	5.25	59.88	16.01	13.10	2.06	6,110	9.21	41.78	35.31	Carboniferous	"Coal Meas."	
43	Mo. 1	Sprague	B.	.99	5.53	4.64	60.00	8.46	20.38	2.08	6,191	3.50	40.77	35.35	do	do	
44	Ill. 6	Coffeen	B.	1.23	4.45	4.88	60.51	14.20	14.73	2.09	6,199	5.13	47.46	32.68	do	do	Run of mine.
44a	Wyo. 3693	Labarge Range	S.	1.03	2.10	5.74	61.76	25.96	3.41	2.10	a6,057	10.78	43.94	40.46	Cretaceous	Montana	Prospect.
44b	Mont. 3515	Belt district	B.	.69	3.80	4.02	62.51	9.16	19.82	2.11	6,094	1.93	51.44	26.81	do	Kootenai	Country bank.
45	Ill. 23A	Donkville	B.	1.04	4.58	4.55	60.93	10.94	17.96	2.11	6,180	2.86	43.14	36.04	Carboniferous	"Coal Meas."	Lump.
46	Wash. 1	Renton	S.	1.30	.68	4.91	63.28	16.92	12.91	2.12	6,182	5.98	45.96	35.15	Eocene		Pea coal; car sample.
46a	Colo. 4050	Near Glenwood Springs.	B.	1.58	.98	5.04	62.74	19.71	9.95	2.12	6,226	7.05	47.60	35.40	Cretaceous	Mesaverde	Mine sample.
47	Ill. 21B	Troy	B.	1.24	1.17	5.14	62.84	17.26	12.35	2.12	6,278	8.52	46.95	32.18	Carboniferous	"Coal Meas."	
48	Iowa 2	Hamilton	B.	1.46	5.20	4.84	60.36	11.15	16.99	2.14	6,212	4.25	41.75	37.02	do	do	Run of mine.
49	Ill. 7B	Collinsville	B.	1.03	4.69	5.14	60.71	14.77	13.66	2.14	6,229	7.60	41.19	37.55	do	do	
50	Wash. 1B	Renton	S.	1.29	.80	5.16	63.35	16.82	12.58	2.15	6,273	5.20	45.68	36.54	Eocene		Run of mine; car sample.
51	Ind. 1	Mildred	B.	1.22	2.58	5.20	62.20	14.99	13.81	2.16	6,336	8.66	42.67	39.86	Carboniferous	"Coal Meas."	Run of mine.
51a	Philip	Batan Island	S.	1.33	1.36	5.55	62.91	23.29	5.56	2.17	a6,101	7.06	43.44	43.94	Miocene?		Probably oxidized.
52	Iowa 4	Centerville	B.	.94	4.46	5.31	61.25	16.56	11.48	2.18	6,237	10.03	41.22	37.27	Carboniferous	"Coal Meas."	Lump.
52a	N. Mex. 3952	Near Blackrock	B.	1.03	1.54	5.45	63.00	12.36	16.62	2.18	6,500	4.01	40.22	39.12	Cretaceous	Mancos	Mine sample (?).
52b	Wyo. 2325	Almy	S.	1.23	.22	4.97	64.28	21.56	7.73	2.19	6,220	7.73	44.52	39.45	Tert.-Cret.?	Evanston	Mine.
52c	Colo. 3463	Lay	B.	1.16	1.05	5.50	63.43	22.37	6.49	2.19	6,198	9.87	46.97	36.67	Cretaceous	Mesaverde	Prospect.
53	Ill. 25B	Germantown	B.	1.12	5.06	5.05	60.96	13.57	14.24	2.19	6,337	5.79	43.18	37.79	Carboniferous	"Coal Meas."	Lump.
53a	Wyo. 3917	Near Fort Steele	S.	1.56	.85	5.16	63.57	25.05	3.80	2.20	6,310	8.70	48.44	39.05	Cretaceous	Lewis	Shaft.
54	Ill. 9C	Staunton	B.	.95	4.39	4.31	62.23	10.41	17.71	2.21	6,273	2.25	47.09	32.95	Carboniferous	"Coal Meas."	
55	Ill. 22A	Maryville	B.	1.06	5.68	4.83	60.94	13.66	13.83	2.21	6,267	6.39	41.89	37.89	do	do	Lump.
55a	Wyo. 3698	Labarge Range	S.	1.08	.84	5.68	63.81	25.75	2.84	2.23	a6,258	10.22	45.98	39.47	Cretaceous	Montana	Drift.

56	Wyo. 4B	Hanna	S.	.88	.27	6.18	64.01	21.62	7.04	2.23	6,183	8.94	42.70	41.32	Tertiary	Fort Union	Mine; car sample.
57	Ill. 29B	Livingston	B.	.85	4.68	5.11	61.69	14.62	13.05	2.23	6,302	7.14	44.09	35.72	Carboniferous.	"Coal Meas."	Run of mine.
57a	Wyo. 3605	Hanna	S.	1.29	.50	5.41	64.07	21.58	7.14	2.23	6,420	8.07	42.85	41.93	Tertiary	Fort Union	Top bench No. 1; mine sample.
58	Ill. 6B	Coffeen	B.	1.10	4.67	4.69	61.96	12.15	15.43	2.24	6,229	4.17	47.77	32.63	Carboniferous.	"Coal Meas."	Run of mine.
59	Ill. 29	Livingston	B.	1.08	4.71	4.92	61.67	14.07	13.55	2.24	6,393	5.58	45.14	35.73	do	do	
60	Iowa 1	Laddsdale	B.	.97	5.20	4.61	61.80	10.90	16.52	2.25	6,329	5.21	46.51	31.76	do	do	Lump.
61	Ill. 1	O'Fallon	B.	1.07	4.25	5.09	62.01	13.86	13.72	2.25	6,360	6.28	41.08	38.92	do	do	Screened.
62	Ill. 15	Centralia	B.	1.09	4.04	4.99	62.25	13.82	13.81	2.25	6,356	6.00	43.91	36.28	do	do	Coarse coal.
62a	Utah 4013	Near Sunnyside	B.	1.30	.47	4.71	64.88	20.11	8.53	2.26	6,293	5.12	53.21	33.14	Cretaceous	Mesaverde	From prospect.
63	Iowa 3	Altoona	B.	.93	6.83	4.93	60.62	11.16	15.53	2.27	6,309	4.52	38.99	40.96	Carboniferous.	"Coal Meas."	Lump.
64	N. Mex. 1	Gallup	S.	1.05	.64	5.73	64.34	21.14	7.10	2.28	6,353	10.86	46.90	35.14	Cretaceous	Mesaverde	Mine; car sample.
65	Kans. 2B	Yale	B.	1.11	5.03	4.26	62.65	5.13	21.82	2.32	6,329	1.51	48.42	28.25	Carboniferous.	"Coal Meas."	Run of mine.
66	Ind. 14	Seelyville	B.	.97	5.34	4.99	62.05	11.90	14.75	2.33	6,430	4.34	42.64	38.27	do	do	Do.
66a	Colo. 3498	Meeker	B.	1.26	.76	5.20	64.95	20.41	7.42	2.33	6,446	7.18	46.50	38.90	Cretaceous	Mesaverde	Mine sample.
67	Ind. 13	Terre Haute	B.	.87	3.37	5.25	63.39	14.31	12.81	2.34	6,414	7.62	42.02	37.55	Carboniferous.	"Coal Meas."	Run of mine.
68	Ind. 4	Star City	B.	1.24	2.59	4.66	64.10	11.36	16.05	2.34	6,426	3.58	47.41	32.96	do	do	Sampled.
69	Ill. 30	Shiloh station	B.	1.03	4.80	4.92	62.60	12.20	14.45	2.35	6,510	3.27	43.18	39.10	do	do	Coal No. 6.
70	Ill. 21	Troy	B.	1.22	1.55	4.94	64.76	15.34	12.20	2.35	6,514	5.74	47.17	34.89	do	do	Lump.
71	Ill. 22B	Maryville	B.	1.00	4.90	4.52	62.99	10.23	16.36	2.36	6,376	2.06	44.81	36.77	do	do	Screenings.
72	Ind. T. 4	Lehigh	B.	1.38	4.02	4.84	63.21	13.15	13.40	2.38	6,327	4.91	43.90	37.79	do	do	Lump.
72a	Colo. 3545	Book Cliffs district	B.	1.47	.66	5.58	65.05	20.96	6.28	2.38	[b]6,312	10.00	50.98	32.74	Cretaceous	Mesaverde	Prospect.
73	Ill. 31	Worden	B.	1.14	4.05	4.83	63.47	11.84	14.67	2.39	6,394	3.77	45.94	35.62	Carboniferous.	"Coal Meas."	Screenings.
73a	Colo. 3490	Book Cliff field	B.	1.13	.89	5.13	65.51	16.92	10.42	2.39	6,532	6.17	47.13	36.28	Cretaceous	Mesaverde	Mine sample.
73b	Mont. 4115	Stockett district	B.	.92	2.43	4.33	65.17	12.66	14.49	2.40	6,348	3.70	52.68	29.13	do	Kootenai	Do.
73c	Wyo. 2283	Mammoth Holl	S.	1.03	.58	5.24	65.76	23.96	3.43	2.40	6,385	7.57	47.20	40.49	do	Montana	Mine; shallow.
74	Ind. 2	Boonville	B.	1.25	4.60	5.11	62.97	12.56	13.51	2.41	6,410	6.24	42.76	37.49	Carboniferous.	"Coal Meas."	Run of mine.
75	Ind. 17	Bicknell	B.	.94	3.85	5.03	63.70	14.87	11.61	2.41	6,446	7.36	46.80	34.23	do	do	Do.
75a	Colo. 3462	Lay	B.	1.22	1.14	5.53	65.33	20.41	6.37	2.44	[b]6,419	8.66	47.29	37.68	Cretaceous	Mesaverde	Outcrop.
75b	Colo. 3704	Axial	B.	1.40	.54	5.24	66.12	21.92	4.78	2.48	6,534	8.91	49.22	37.09	do	do	Mine sample.
76	Ill. 14	Springfield	B.	1.19	4.52	5.00	63.85	12.64	12.80	2.50	6,496	5.13	44.31	37.70	Carboniferous.	"Coal Meas."	Lump.
77	Ohio 3	Shawnee	B.	1.28	1.88	5.05	65.62	14.12	12.05	2.51	6,519	6.24	46.68	35.03	do	do	Sample.
78	Ill. 12	Bush	B.	1.14	3.61	4.86	64.85	12.11	13.43	2.54	6,548	4.77	48.34	33.46	do	do	Run of mine.
79	Kans. 2	Yale	B.	.94	6.40	4.56	63.14	6.69	18.27	2.54	6,600	2.23	47.63	31.87	do	do	Do.
80	Ind. 6	Hymera	B.	1.19	4.63	5.15	64.22	11.50	13.31	2.58	6,555	5.91	42.71	38.07	do	do	Do.
81	Ill. 9A	Staunton	B.	1.04	4.43	5.18	64.49	13.06	11.80	2.59	6,538	4.99	43.99	39.22	do	do	Do.
81a	Ariz. 4112	Near St. Michaels	B.	1.28	.42	5.75	66.81	21.69	4.05	2.59	6,723	9.89	46.95	39.07	Cretaceous	Mesaverde	
82	Ill. 26	Lincoln	B.	1.21	4.02	4.75	65.02	11.15	13.85	2.60	6,579	3.41	45.62	37.12	Carboniferous.	"Coal Meas."	Do.
83	Wyo. 6	Kemmerer	S.	1.10	.55	5.81	66.95	22.07	3.52	2.61	[d]6,456	8.68	46.49	41.31	Cretaceous	Montana	Run of mine; car sample.
84	Ill. 19E	Ziegler	B.	1.53	.54	4.54	67.48	14.99	10.92	2.61	6,625	5.27	52.58	31.23	Carboniferous.	"Coal Meas."	Screened.
84a	Colo. 3703	Axial	B.	1.12	.60	5.20	67.42	22.64	3.02	2.62	6,654	8.67	49.99	38.32	Cretaceous	Mesaverde	Old drift sample.
85	Ala. 2B	Carbon Hill	B.	1.52	1.14	4.46	67.35	10.69	14.84	2.63	6,660	2.29	51.64	31.23	Carboniferous.	Pottsville	Run of mine.
86	N. Mex. 3A	Van Houten	B.	1.25	.74	4.83	67.54	8.63	17.01	2.63	6,742	1.48	48.80	32.71	Cretaceous	Montana	Mine.
87	Ind. 16	Linton	B.	1.13	4.50	5.02	64.82	12.04	12.49	2.64	6,623	4.68	44.24	38.59	Carboniferous.	"Coal Meas."	Run of mine.
88	Kans. 6	Jewett	B.	1.14	4.00	4.54	65.65	7.75	16.92	2.66	6,663	2.09	49.03	31.96	do	do	Lump.
89	Tenn. 9B	Coalmont	B.	1.26	.78	4.72	67.76	6.01	19.47	2.66	6,693	1.03	52.89	26.61	do	Pottsville	Slack.
90	Mo. 5	Higbee	B.	1.02	5.68	4.69	64.52	8.72	15.37	2.67	6,614	1.71	44.95	37.97	do	"Coal Meas."	Run of mine.
91	Ind. 12	Hartwell	B.	1.25	4.13	5.01	65.28	11.88	12.45	2.68	6,688	4.45	45.68	37.42	do	do	Do.
92	Ohio 2	Superior	B.	1.25	4.17	5.17	65.14	12.51	11.76	2.68	6,625	5.61	45.44	37.19	do	do	Do

[a] From shallow mine or country bank. [b] Coals more or less weathered. [c] Sample probably deteriorated. [d] Car sample.

TABLE 1.—*Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C: (O+ash) ratio of each coal*—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C / O+ash	Calories.	Moisture.	Fixed carbon.	Volatile matter.	Age.	Formation.	Remarks.
93	N. Mex. 3B	Van Houten	B.	1.22	.86	4.60	68.00	8.91	16.41	2.68	6,823	1.40	48.98	33.21	Cretaceous	Montana	Mine.
94	Ill. 23B	Donkville	B.	1.03	4.98	4.91	65.10	10.95	13.03	2.71	6,598	2.23	45.93	38.81	Carboniferous	"Coal Meas."	Slack.
95	Ill. 19C	Ziegler	B.	1.49	.54	5.10	67.91	13.53	11.43	2.72	6,596	6.01	52.23	30.33	do	do	Run of mine.
96	Ill. 24A	New Baden	B.	1.10	5.33	4.94	64.86	12.20	11.57	2.72	6,575	4.36	47.43	36.64	do	do	Screenings.
97	Ill. 3	Marion	B.	1.43	1.77	4.92	67.30	12.99	11.59	2.74	6,724	5.96	52.16	30.29	do	do	Run of mine; No. 6.
98	Ind. 5	Hymera	B.	1.16	4.60	5.07	65.44	12.01	11.72	2.75	6,700	5.21	44.65	38.42	do	do	Run of mine.
99	Ill. 9B	Staunton	B.	1.09	4.40	5.14	65.57	12.32	11.48	2.75	6,717	4.03	44.18	40.31	do	do	Lump.
100	N. Mex. 3C	Van Houten	B.	1.20	.65	4.75	68.66	9.00	15.74	2.77	6,855	1.37	49.23	33.66	Cretaceous	Montana	Mine.
101	Ind. 11	Dugger	B.	1.44	1.47	5.22	67.63	15.76	8.48	2.79	6,806	8.49	48.16	34.87	Carboniferous	"Coal Meas."	Lump.
101a	Colo. 3550	Book Cliffs field	B.	1.26	.63	5.19	68.46	13.25	11.21	2.79	6,757	4.30	47.53	33.32	Cretaceous	Mesaverde	Mine sample.
102	Ind. 9	Maxville	B.	1.12	3.56	5.19	66.48	12.46	11.20	2.81	6,714	5.24	45.73	37.83	Carboniferous	"Coal Meas."	Lump.
103	Ind. 18B	Winston	B.	1.18	1.49	5.50	67.95	16.80	7.08	2.84	6,881	8.92	48.57	35.43	do	do	Do.
104	Ill. 34B	Harrisburg	B.	1.38	2.96	4.69	67.29	10.95	12.73	2.84	6,883	2.92	51.25	33.10	do	do	Run of mine.
105	Ohio 1	Wellston	B.	1.17	4.85	5.12	65.70	10.59	12.57	2.84	6,727	2.96	44.18	40.29	do	do	Do.
106	Ill. 19	Ziegler	B.	1.48	.57	4.85	69.05	14.23	9.82	2.86	6,697	6.39	54.46	29.33	do	do	Sized coal.
107	Ind. 9B	Maxville	B.	1.19	3.53	5.14	66.79	11.30	12.05	2.86	6,811	3.17	45.81	38.97	do	do	Run of mine.
108	Ky. 4	Wheatcroft	B.	1.28	4.67	4.53	66.50	8.43	14.59	2.88	6,830	2.54	46.79	36.08	do	do	Do.
109	Ohio 9B	Clarion	B.	1.12	3.55	4.80	67.31	10.58	12.64	2.89	6,805	2.65	45.65	39.06	do	do	Slack.
110	Ill. 10	West Frankfort	B.	1.46	1.56	4.88	68.56	11.25	12.29	2.89	6,866	2.79	50.57	34.35	do	do	Do.
110a	Wyo. 3891	McDougals Mountain.	B.	1.38	.33	5.31	69.07	18.99	4.92	2.89	6,879	6.50	48.42	39.95	Cretaceous	Benton	Prospect; new.
111	Ky. 3	Barnsley	B.	1.43	3.60	5.27	66.75	12.66	10.29	2.92	6,829	5.85	46.96	36.90	Carboniferous	"Coal Meas."	Run of mine.
112	Ill. 12B	Bush	B.	1.02	2.60	4.80	68.30	11.74	11.54	2.93	6,756	3.97	51.43	33.06	do	do	Do.
112a	Wyo. 3509	Fort Steele	B.	1.79	.88	5.17	68.93	17.24	5.99	2.96	6,759	5.72	49.76	38.53	Cretaceous	Mesaverde	Mine.
113	Mo. 6	Huntsville	B.	1.08	6.34	4.74	65.71	8.85	13.28	2.96	6,785	2.49	45.44	38.79	Carboniferous	"Coal Meas."	Lump.
114	Ala. 2	Carbon Hill	B.	1.55	1.02	4.79	69.24	10.87	12.53	2.96	6,916	2.58	51.74	33.15	do	Pottsville	Sized.
115	Ind. T. 8	(?)	B.	1.64	1.93	4.67	68.65	8.86	14.25	2.97	6,837	2.29	50.21	33.25	do	"Coal Meas."	Car sample.
116	Ill. 12C	Bush	B.	1.19	2.65	4.83	68.36	11.02	11.95	2.97	6,862	3.32	51.70	33.03	do	do	Run of mine.
117	Ind. 8	Terre Haute	B.	1.13	3.90	5.21	67.17	11.47	11.12	2.97	6,848	5.19	45.76	37.93	do	do	Lump; deep coal.
118	N. Mex. 4B	Brilliant	B.	1.53	.62	4.97	69.48	8.62	14.78	2.97	6,927	1.40	49.02	34.80	Cretaceous	Montana	Screenings.
119	Ill. 11B	Carterville	B.	1.37	2.62	4.88	68.25	10.50	12.38	2.99	6,901	3.25	51.19	33.18	Carboniferous	"Coal Meas."	Mixed.
120	Ill. 18	La Salle	B.	1.09	4.28	5.37	66.91	12.61	9.74	2.99	6,914	4.36	45.63	40.27	do	do	Lump.
121	Ala. 5	Lehigh	B.	1.33	1.46	4.40	69.64	6.35	16.82	3.00	6,920	1.24	55.74	26.20	do	Pottsville	Run of mine.
122	Ill. 13	Benton	B.	1.55	1.62	4.90	69.00	11.94	10.99	3.00	6,829	3.89	51.94	33.18	do	"Coal Meas."	Egg coal.
123	Ark. 1B	Huntington	Sb.	1.46	1.14	3.86	70.25	4.03	19.26	3.01	6,770	.85	63.64	16.25	do	do	Slack.
124	Ill. 28C	Herrin	B.	1.25	1.36	4.88	69.54	12.68	10.29	3.02	6,849	4.93	54.11	30.77	do	do	Lump.
125	Ind. T. 2B	Hartshorne	B.	1.72	1.88	4.51	69.15	7.71	15.03	3.04	6,915	1.44	49.49	34.04	do	do	Slack.
126	N. Mex. 4A	Brilliant	B.	1.53	.62	5.03	69.86	9.19	13.77	3.04	7,034	1.71	49.25	35.23	Cretaceous	Montana	Mine.
127	Ill. 12D	Bush	B.	1.22	2.70	4.75	68.81	11.54	10.98	3.05	6,910	2.97	53.54	32.51	Carboniferous	"Coal Meas."	

128	Wash. 2	Roslyn	B.	1.26	.38	5.08	70.26	10.60	12.42	3.05	7,084	1.88	48.73	36.97	Eocene		Do.
129	Ky. 7	Central City	B.	1.32	2.71	5.06	67.80	12.34	9.77	3.06	6,863	5.64	48.26	36.33	Carboniferous.	"Coal Meas."	Lump.
130	Ky. 2	Earlington	B.	1.25	3.72	5.33	67.64	12.08	9.38	3.06	6,966	5.36	46.27	38.99	do	do	Coarse coal.
131	Ohio 11	Flushing	B.	1.19	4.39	4.71	67.72	8.84	13.15	3.08	6,937	1.87	48.35	36.63	do	do	Lump.
132	Ind. 18A	Winslow	B.	1.38	1.69	5.48	69.08	15.17	7.20	3.08	6,898	8.29	48.28	36.23	do	do	Slack.
133	Ky. 9A	McHenry	B.	1.24	3.25	5.41	68.01	12.80	9.29	3.08	6,953	5.39	49.05	36.27	do	do	Nut.
134	Ala. 3	Garnsey	B.	1.15	.56	4.47	70.84	8.45	14.53	3.08	7,007	1.54	54.11	29.82	do	Pottsville	Run of mine.
134a	Colo. 3541	Book Cliffs field	B.	1.58	.87	5.14	69.83	16.47	6.11	3.09	6,978	5.63	51.49	36.77	Cretaceous	Mesaverde	Mine sample.
135	Ky. 9B	McHenry	B.	1.39	3.10	5.07	68.35	11.59	10.50	3.09	6,985	3.91	51.49	34.10	Carboniferous.	"Coal Meas."	Run of mine.
135a	Ill. 19B	Ziegler	B.	1.56	.64	4.51	70.55	13.11	9.63	3.10	6,897	3.87	55.19	31.31	do	do	Lump No. 6.
136	Ind. 15	Linton	B.	1.56	1.00	5.11	69.89	13.47	8.97	3.11	6,979	4.93	50.82	35.28	do	do	Run of mine.
136a	Colo. 3640	Book Cliffs field	B.	1.20	.49	5.38	70.32	16.87	5.74	3.11	6,908	5.21	55.69	33.36	Cretaceous	Mesaverde	Shallow; mine sample.
137	Ind. T. 3	Edwards	B.	1.50	3.67	4.85	68.18	10.52	11.28	3.12	6,927	3.45	47.82	37.45	Carboniferous.	"Coal Meas."	Run of mine.
138	Kans. 4	Atchison	B.	1.07	8.33	5.04	65.02	7.91	12.63	3.16	6,854	3.57	46.80	37.00	do	do	Lump.
139	Ill. 16	Herrin	B.	1.56	1.19	4.94	70.14	12.17	10.00	3.16	6,921	4.61	54.05	31.35	do	do	Do.
140	Va. 5A	Blacksburg	Sa.	.69	.66	3.60	72.23	4.02	18.80	3.16	6,929	.73	69.92	10.55	do	Pocono	
141	N. Mex. 5	Blossburg	B.	1.19	.70	4.79	70.95	7.59	14.78	3.17	7,065	1.34	51.58	32.30	Cretaceous	Montana	Mine.
142	Ind. 7	Littles	B.	1.25	3.88	5.40	67.90	11.93	9.55	3.17	6,920	5.50	44.99	39.96	Carboniferous.	"Coal Meas."	Lump.
143	Kans. 1	Fleming	B.	1.09	4.34	4.91	68.22	8.30	13.14	3.18	6,891	3.74	50.01	33.11	do	do	
144	Wyo. 5	Rock Springs	S.	1.52	.86	5.37	70.30	18.32	3.63	3.20	6,955	6.00	51.68	38.69	Cretaceous	Montana	Mine; car sample.
145	Ill. 11	Carterville	B.	1.39	2.07	4.84	69.91	10.64	11.15	3.21	6,978	3.11	52.71	33.03	Carboniferous.	"Coal Meas."	
146	Ind. T. 1	Henryetta	B.	1.29	1.99	5.14	69.85	11.38	10.35	3.21	7,011	3.87	50.05	35.73	do	do	
146a	Colo. 3946	Rifle Creek	B.	1.63	.71	5.32	70.39	16.47	5.48	3.21	7,075	4.24	53.04	37.24	Cretaceous	Mesaverde	Mine sample.
146b	Colo. 3586	Book Cliffs field	B.	1.63	1.31	5.33	70.00	15.34	6.39	3.22	7,024	4.84	50.49	38.28	do	do	Prospect.
146c	Wyo. 4302	Willow Creek	B.	1.55	.64	4.65	71.09	15.74	6.33	3.22	6,911	4.51	54.85	34.20	do	Benton	Do.
147	Ill. 19B	Ziegler	B.	1.48	.96	4.96	70.70	11.98	9.92	3.23	6,877	5.42	53.03	31.63	Carboniferous.	"Coal Meas."	Lump.
147a	Colo. 3943	Rifle Creek	B.	1.60	1.14	5.36	70.20	15.63	6.07	3.23	7,072	4.31	51.93	37.69	Cretaceous	Mesaverde	Mine sample.
147b	Cal. 3773	Stone Canyon	B.	1.19	4.26	6.18	67.50	14.50	6.37	3.24	7,086	4.86	41.03	47.74	Miocene		Do.
148	Ohio 7	Danford	B.	1.23	3.21	5.14	69.19	10.40	10.83	3.26	6,947	4.16	50.17	34.84	Carboniferous.	"Coal Meas."	
149	Ind. 7B	Littles	B.	1.24	4.14	5.11	68.94	10.34	10.23	3.34	7,020	2.76	46.55	40.46	do	do	Screenings.
149a	Colo. 3546	Book Cliffs field	B.	1.60	.74	5.38	71.03	15.16	6.09	3.34	7,069	5.49	54.10	34.32	Cretaceous	Mesaverde	Deep prospect.
150	Tenn. 6	Waldencia	B.	1.01	.80	4.66	72.14	6.53	14.86	3.37	7,159	1.02	55.69	28.43	Carboniferous.	Pottsville	Run of mine.
151	Tenn. 9A	Coalmont	B.	1.32	.96	4.64	71.84	6.78	14.46	3.38	7,135	1.36	56.22	27.96	do	do	Lump.
152	R. I. 1	Providence	G.	.17	.07	.69	76.63	2.99	19.45	3.41	6,229	.42	75.11	5.02	do	"Coal Meas."	Not a fuel.
153	Ind. 10	Rosedale	B.	1.26	4.17	5.40	69.07	10.77	9.33	3.43	7,113	2.85	45.07	42.75	do	do	Lump.
154	Ohio 8	Dixie	B.	1.35	2.97	5.21	70.18	11.52	8.76	3.46	7,055	3.19	48.26	39.79	do	do	Run of mine.
154a	Wyo. 3480	Fort Steele	B. ?	1.79	.95	5.56	71.24	16.73	3.71	3.48	[a]6,951	5.45	52.89	37.95	Cretaceous	Mesaverde	Weathered in mine.
155	Tenn. 1	Fork Ridge	B.	1.65	1.63	4.95	71.36	8.92	11.49	3.48	7,199	1.87	52.71	33.93	Carboniferous.	Pottsville	Run of mine.
156	Pa. 13	Creighton	B.	1.23	2.19	5.02	71.25	6.96	13.35	3.50	7,221	1.27	51.89	33.49	do	"Coal Meas."	Do.
157	Tenn. 8B	Clifty	B.	1.25	4.84	4.55	69.59	5.36	14.41	3.52	7,096	1.14	50.87	33.58	do	Pottsville	Do.
158	Tenn. 7A	Wilder	B.	1.29	3.32	4.92	70.46	6.94	13.07	3.52	7,122	1.36	50.06	35.51	do	do	Lump.
159	Ala. 1	Horse Creek	B.	1.66	.73	4.96	72.16	7.85	12.64	3.52	7,199	1.56	53.71	32.10	do	do	Sized.
160	Ind. T. 2	Hartshorne	B.	1.72	1.56	5.00	71.49	8.91	11.32	3.53	7,205	1.70	49.79	37.19	do	"Coal Meas."	Run of mine.
160a	Colo. 3936	Newcastle	B.	1.40	.44	5.07	72.65	13.49	6.95	3.55	7,243	2.81	53.25	36.99	Cretaceous	Mesaverde	Mine sample.
161	Ga. 1	Menlo	Sb.	1.13	1.31	4.09	72.92	5.58	14.97	3.55	7,341	.62	68.01	16.40	Carboniferous.	Pottsville	Lump.
161a	Wyo. 4323	Greys	B.	1.48	.28	5.14	72.97	18.45	1.68	3.62	7,358	4.20	56.36	37.60	Cretaceous	Benton	Prospect.
162	Va. 5B	Blacksburg	Sa.	.74	.70	3.85	74.33	2.91	17.47	3.65	7,112	.45	71.00	11.08	Carboniferous.	Pocono	
163	Pa. 3	Scranton	A.	.80	.77	2.81	75.21	4.08	16.33	3.68	6,929	2.08	74.32	7.27	do	"Coal Meas."	Waste culm.

[a] Coals more or less weathered.

TABLE 1.—*Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C: (O+ash) ratio of each coal*—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C / O+ash	Calories.	Moisture.	Fixed carbon.	Volatile matter.	Age.	Formation.	Remarks.
164	Tenn. 8A	Clifty	B.	1.17	4.45	4.97	70.45	5.50	13.64	3.68	7,179	1.05	51.26	34.05	Carboniferous.	Pottsville	Lump.
165	Ill. 34A	Harrisburg	B.	1.53	2.51	4.96	71.55	10.55	8.90	3.68	7,324	2.13	53.36	35.61	do	"Coal Meas."	Screenings.
166	Ala. 4	Belle Ellen	B.	1.25	1.14	4.89	73.09	5.96	13.67	3.72	7,287	.98	55.13	30.22	do	Pottsville	Run of mine.
166a	Colo. 3587	Book Cliffs field	B.	1.65	1.08	5.64	72.46	13.12	6.05	3.77	a7,207	4.17	52.20	37.58	Cretaceous	Mesaverde	Country bank.
167	Ohio 12B	Bellaire	B.	1.25	3.70	5.07	71.13	8.75	10.10	3.77	7,280	1.69	50.10	38.11	Carboniferous.	"Coal Meas."	
168	Ohio 10	Mineral City	B.	1.32	3.00	5.55	71.28	11.14	7.71	3.78	7,368	2.24	48.55	41.50	do	do	Lump.
169	Pa. 6	East Millsboro	B.	1.27	1.98	4.67	72.87	6.43	12.78	3.78	7,301	1.27	53.52	32.43	do	do	Run of mine.
170	Ill. 11C	Carterville	B.	1.43	1.76	4.99	72.80	10.84	8.18	3.82	7,263	2.36	54.84	34.62	do	do	
171	Ohio 9A	Clarion	B.	1.22	3.25	4.67	72.07	10.23	8.56	3.83	7,331	2.47	50.89	38.08	do	do	Lump.
171a	Colo. 3338	Newcastle	B.	1.76	.54	5.05	73.45	14.22	4.98	3.83	7,429	2.73	53.60	38.69	Cretaceous	Mesaverde	Mine sample.
171b	Colo. 3585	Book Cliffs field	B.	1.63	1.37	5.52	72.62	13.53	5.33	3.85	7,182	4.78	52.69	37.20	do	do	Do.
171c	Colo. 3332	Newcastle	B.	1.45	.42	5.21	73.98	13.53	5.41	3.91	7,364	3.19	55.49	35.91	do	do	Do.
172	Ohio 12A	Bellaire	B.	1.23	4.07	5.03	71.44	8.60	9.63	3.92	7,343	1.58	48.44	40.35	Carboniferous.	"Coal Meas."	Run of mine.
173	Kans. 5	West Mineral	B.	1.09	3.86	4.96	71.90	7.40	10.79	3.95	7,333	1.84	54.97	32.40	do	do	Screened.
173a	Wyo. 3570	Oyster Ridge	B.	1.18	.48	5.10	74.41	14.36	4.47	3.95	7,336	3.84	55.47	36.06	Cretaceous	Benton	Prospect.
173b	Colo. 3939	Newcastle	B.	1.73	.52	5.17	73.87	13.62	5.09	3.95	7,441	2.90	53.35	38.66	do	Mesaverde	Mine sample.
174	Tenn. 4	Oliver Springs	B.	1.63	1.03	5.13	73.62	8.58	10.00	3.96	7,333	1.77	54.32	33.91	Carboniferous.	Pottsville	Run of mine.
174a	Colo. 4036	North of Sunlight	B.	1.78	.53	5.49	73.65	16.61	1.94	3.97	7,465	4.18	54.63	39.25	Cretaceous	Mesaverde	Mine sample.
175	W. Va. 22B	Hernshaw	B.	1.18	1.04	5.06	74.16	8.47	10.09	3.99	7,344	1.74	53.80	34.37	Carboniferous.	Pottsville?	Run of mine.
175a	Colo. 4225	Near Mancos	B.	1.50	1.03	5.69	73.73	12.18	5.87	4.08	a7,316	3.51	51.12	39.50	Cretaceous	Mesaverde	Shallow mine.
176	Pa. 17	White	B.	1.44	1.56	4.83	74.06	5.80	12.31	4.08	7,448	1.09	57.87	28.71	Carboniferous.	"Coal Meas."	Run of mine.
176a	Colo. 7573	Hesperus	B.	1.40	.66	5.32	74.41	12.39	5.82	4.08	7,461	3.33	53.77	37.08	Cretaceous	Mesaverde	Mine sample.
177	W. Va. 25	Spring Hill	B.	1.43	.66	5.02	74.61	10.89	7.39	4.08	7,608	1.95	54.42	36.24	Carboniferous.	"Coal Meas."	Lump.
178	Ohio 4	Crow Hollow	B.	1.33	3.52	5.06	72.68	8.16	9.25	4.17	7,365	2.16	50.61	37.98	do	do	Screened.
179	Ark. 8	Spadra	Sa.	.53	2.14	3.44	75.77	3.47	14.65	4.18	7,244	.83	73.55	10.97	do	do	Stove coal.
179a	Colo. 4048	Sunlight	B.	1.86	.96	5.36	74.10	14.72	3.00	4.18	7,564	3.10	55.32	38.58	Cretaceous	Mesaverde	"D" bed.
180	Ky. 8	Sturgis	B.	1.23	1.22	4.87	74.99	9.51	8.18	4.24	7,598	2.33	57.48	32.01	Carboniferous.	"Coal Meas."	Run of mine.
181	Ark. 12	(?)	Sb.	1.38	1.68	3.78	75.49	4.15	13.52	4.27	7,282	1.22	68.58	16.68	do	do	Slack.
182	Ark. 1	Huntington	Sb.	1.47	1.27	4.00	75.68	4.70	12.88	4.30	7,450	1.17	68.12	17.83	do	do	
183	Ohio 5	Rush Run	B.	1.45	1.76	5.06	74.44	9.81	7.48	4.31	7,501	1.99	54.13	36.40	do	do	Screened.
184	Utah 1	Price	B.	1.43	.57	5.55	75.18	12.21	5.06	4.35	7,595	2.34	48.92	43.68	Cretaceous	Mesaverde	
185	Tenn. 5	Petros	B.	1.69	3.38	4.97	73.23	6.53	10.20	4.37	7,456	1.35	53.32	35.13	Carboniferous.	Pottsville	Run of mine.
186	Tenn. 3	Gatliff	B.	1.78	1.02	5.31	74.80	9.81	7.28	4.38	7,489	2.25	54.79	35.68	do	do	Do.
187	Ohio 6	Neffs	B.	1.17	3.47	5.16	73.58	7.76	8.87	4.42	7,425	1.47	51.45	38.21	do	"Coal Meas."	Do.
188	Ind. T. 2C	Hartshorne	B.	1.88	1.25	5.03	74.50	8.87	8.87	4.45	7,505	1.43	53.68	36.62	do	do	Lump.
189	Pa. 22	Huff	B.	1.58	1.03	4.77	75.69	6.44	10.49	4.47	7,632	.91	59.57	29.03	do	do	Run of mine.
190	Md. 1	Georges Creek	Sb.	1.32	1.51	3.88	76.28	3.09	13.32	4.48	7,469	.94	69.40	16.34	do	do	
191	Pa. 12	Acheson	B.	1.46	2.21	4.76	74.89	7.36	9.32	4.49	7,621	1.27	58.64	30.77	do	do	Do.
192	W. Va. 22A	Hernshaw	B.	1.22	.85	5.05	76.01	8.89	7.98	4.50	7,645	1.45	56.40	34.17	do	Pottsville	Screenings.
193	Pa. 7	Ligonier	B.	1.55	2.15	4.51	75.19	3.72	12.88	4.52	7,549	.92	64.90	21.30	do	"Coal Meas."	Run of mine.

194	Tenn. 9C	Coalmont	B.	1.28	.07	4.83	76.37	7.27	9.58	4.54	7,563	1.43	59.26	29.73	do	Pottsville	Slack.
195	Ark. 3	Jenny Lind	Sb.	1.55	1.30	4.07	76.37	4.91	11.80	4.57	7,586	.80	67.65	19.75	do	"Coal Meas."	
196	Pa. 21	Connelsville	B.	1.57	.90	4.63	76.34	7.47	9.09	4.61	7,751	.97	60.85	29.09	do	do	Run of mine.
197	Pa. 4	Greensburg	B.	1.46	1.29	4.82	76.00	5.78	10.64	4.62	7,616	.97	57.44	30.95	do	do	Lump.
198	W. Va. 3	Richard	B.	1.44	1.07	4.91	76.12	6.09	10.37	4.62	7,631	1.00	58.38	30.25	do	do	Run of mine.
199	W. Va. 23B	Monarch	B.	1.19	1.36	5.04	76.02	8.24	8.15	4.64	7,661	1.46	55.47	34.92	do	Pottsville	Slack.
200	W. Va. 5	Coalton	B.	1.48	.99	4.78	76.36	6.21	10.18	4.65	7,682	.65	59.97	29.20	do	"Coal Meas."	Coarse coal.
201	W. Va. 16	Monongah	B.	1.53	1.26	4.80	76.09	7.56	8.76	4.66	7,609	1.22	56.96	33.06	do	do	Screenings.
202	Pa. 19	Herminie	B.	1.42	1.08	4.92	76.25	7.76	8.57	4.67	7,752	1.01	57.85	32.57	do	do	Run of mine.
203	Mo. 4	Barnet	B.	.75	5.55	5.77	72.45	10.25	5.23	4.68	7,516	5.39	44.47	44.91	do	do	Do.
204	Ky. 1B	Straight Creek	B.	1.73	1.16	5.06	75.89	7.62	8.54	4.69	7,623	1.57	55.14	34.75	do	Pottsville	
205	W. Va. 2	Clarksburg	B.	1.37	3.50	5.09	74.44	7.70	7.90	4.70	7,700	1.46	50.50	40.14	do	"Coal Meas."	Do.
206	Ark. 7A	Midland	Sb.	1.32	2.12	3.99	76.37	3.91	12.29	4.71	7,413	.60	70.00	17.11	do	do	Slack.
207	Tenn. 2	Gatliff	B.	1.81	1.01	5.20	75.97	8.98	7.03	4.74	7,630	1.95	54.05	36.97	do	Pottsville	Run of mine.
208	W. Va. 4B	Bretz	B.	1.60	1.10	4.52	76.72	5.68	10.38	4.77	7,626	1.35	60.88	27.39	do	"Coal Meas."	Do.
208a	Wyo. 4303	Willow Creek	B.	1.31	.94	5.04	76.84	12.64	3.23	4.84	7,812	1.99	57.53	37.18	Cretaceous	Benton	Prospect.
208b	Colo. 4010	Gulch	B.	1.56	.45	5.16	77.05	9.46	6.32	4.88	7,860	1.21	57.30	35.17	do	Mesaverde	Mine sample.
208c	Ala. 3499	Lovick	B.	1.69	1.10	4.89	76.64	7.20	8.48	4.88	7,613	1.19	59.43	30.90	Carboniferous	Pottsville	
209	W. Va. 23A	Monarch	B.	1.45	1.24	5.13	76.57	7.90	7.71	4.90	7,643	1.58	55.50	35.21	do	do	Run of mine.
210	Va. 6	Richlands	B.	1.33	1.27	4.44	77.21	5.45	10.30	4.90	7,757	.65	64.77	24.28	do	do	Do.
210a	Ala. 3745	Coalmont	B.	1.13	.88	5.01	77.40	9.28	6.30	4.96	7,764	1.67	59.11	32.92	do	do	Mine sample.
211	Ark. 5	Coal Hill	Sa.	1.39	2.01	3.74	77.29	3.36	12.21	4.96	7,443	1.28	73.69	12.82	do	"Coal Meas."	
211a	Colo. 3552	Near Durango	B.	1.50	1.38	5.29	76.63	9.89	5.31	5.04	[b]7,676	2.07	54.22	38.40	Cretaceous	Mesaverde	Weathered.
212	Pa. 9	Kimmelton	Sb.	1.29	2.09	4.00	77.42	3.58	11.63	5.09	7,657	.50	70.12	17.75	Carboniferous	"Coal Meas."	Run of mine.
213	W. Va. 11	Zenith	Sb.	1.04	.53	4.03	79.12	3.78	11.50	5.17	7,761	.80	70.80	16.90	do	Pottsville	Run of mine, Pocahontas.
214	Pa. 11	Charleroi	B.	1.45	1.19	5.09	77.32	7.62	7.33	5.17	7,699	1.36	57.03	34.28	do	"Coal Meas."	Run of mine, Pittsburg.
215	W. Va. 15	Clarksburg	B.	1.44	2.56	5.03	76.52	5.82	8.63	5.29	7,743	1.12	52.60	37.65	do	do	Do.
215a	Wyo. 4299	Willow Creek	B.	.85	.71	5.59	78.19	11.18	3.48	5.33	7,718	2.37	57.33	36.79	Cretaceous	Benton	Tunnel.
216	W. Va. 14	Bretz	B.	1.50	.90	4.85	78.21	6.11	8.43	5.37	7,855	.98	61.87	28.72	Carboniferous	"Coal Meas."	Run of mine.
216a	Ala. 3771	Acton basin	[a]B.	1.53	.44	5.15	78.67	8.46	5.75	5.53	7,791	1.86	58.75	33.64	do	Pottsville	Helena coal.
217	Va. 4	Darby	B.	1.35	.81	5.13	78.56	9.73	4.42	5.55	7,902	2.40	55.54	37.64	do	do	Screened.
218	Va. 2B	Crab Orchard	B.	1.45	.94	5.08	78.51	8.33	5.69	5.59	7,890	1.48	57.02	35.81	do	do	Run of mine.
219	W. Va. 1	Kingmont	B.	1.55	.90	5.26	78.31	7.61	6.37	5.60	7,869	1.35	55.36	36.92	do	"Coal Meas."	Do.
220	Pa. 10	Bruce	B.	1.59	1.28	5.14	78.16	7.58	6.25	5.64	7,877	1.33	57.04	35.38	do	do	Nut.
221	Va. 1	Crab Orchard	B.	1.27	1.23	5.17	78.47	9.01	4.85	5.66	7,870	1.70	57.66	35.79	do	Pottsville	Run of mine.
222	W. Va. 20	Acme	B.	1.37	1.41	5.04	78.39	5.59	8.20	5.68	7,812	.74	58.17	32.89	do	do	Do.
223	W. Va. 8	Ansted	B.	1.38	.92	5.16	78.75	6.43	7.36	5.71	7,863	1.60	58.92	32.12	do	do	Do.
224	Ky. 6	Miller Creek	Sp.	1.48	.58	5.35	78.94	10.83	2.82	5.78	7,807	2.99	56.88	37.31	do	do	"Splint."
225	W. Va. 17	Near Bretz	B.	1.41	1.49	4.51	78.95	5.31	8.33	5.78	7,903	1.00	62.68	27.99	do	"Coal Meas."	Prospect.
226	Pa. 5	Ellsworth	B.	1.55	.89	5.20	78.78	7.47	6.11	5.80	7,864	1.47	57.59	34.83	do	do	Screened, Pittsburg.
227	Pa. 16	Hastings	Sb.	1.33	1.65	4.46	79.00	5.37	8.19	5.83	7,812	.36	68.78	22.67	do	do	Run of mine.
227a	Ala. 3769	Acton basin	B.	1.25	1.10	5.01	79.16	8.83	4.65	5.87	7,964	1.62	59.87	33.86	do	Pottsville	Helena coal.
228	Pa. 20	Seward	Sb.	1.16	2.96	4.55	78.23	2.17	10.93	5.90	7,692	.42	72.17	16.48	do	"Coal Meas."	Run of mine.
229	Ky. 1	Straight Creek	B.	1.85	1.24	5.36	78.31	8.80	4.44	5.91	7,955	1.92	57.08	36.56	do	Pottsville	Do.
230	Pa. 15B	Wehrum	Sb.	1.18	4.06	4.29	77.52	2.40	10.55	5.98	7,781	.48	70.49	18.48	do	"Coal Meas."	Do.
231	W. Va. 18	Glen Alum	B.	1.45	.68	4.91	79.65	7.39	5.92	5.98	7,963	1.28	59.03	33.77	do	Pottsville	Do.
231a	Ala. 3744	Fallston	Sb.	1.33	.67	5.26	79.50	10.03	3.21	6.01	8,115	1.52	60.68	34.59	do	do	Buck bed.
231b	Colo. 4047	Coal basin	B.	1.83	.52	4.65	79.77	4.59	8.64	6.03	7,977	.76	69.07	21.53	Cretaceous	Mesaverde	Run of mine.

[a] From shallow mine or country bank.

[b] Coals more or less weathered.

TABLE 1.—*Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C : (O+ash) ratio of each coal*—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C / O+ash	Calories.	Moisture.	Fixed carbon.	Volatile matter.	Age.	Formation.	Remarks.
232	W. Va. 9	Powellton	B.	1.63	.80	5.04	79.35	6.39	6.79	6.03	7,984	1.01	62.67	29.53	Carboniferous.	Pottsville	Run of mine.
233	Ky. 5	Big Black Mountain.	B.	1.61	.69	4.99	79.67	9.23	3.81	6.10	7,958	1.60	58.56	36.03	do	do	"Splint;" prospect.
234	W. Va. 21	Winifrede	B.	1.52	1.35	5.21	79.15	7.83	4.95	6.19	7,915	1.50	56.39	37.16	do	do	Run of mine, Winifrede coal.
235	Ala. 6	Dolomite	B.	1.45	.63	4.84	80.25	5.94	6.88	6.26	8,011	.85	65.47	26.80	do	do	Run of mine, Pratt coal.
236	Ark. 2	Bonanza	Sb.	1.40	1.90	4.13	80.03	3.20	9.34	6.38	7,756	.74	73.66	16.26	do	"Coal Meas."	
237	Pa. 15	Wehrum	Sb.	1.17	3.88	4.43	78.61	1.82	10.09	6.60	7,885	.34	71.45	18.12	do	do	Run of mine.
238	Pa. 18	Lloydell	Sb.	1.23	1.55	4.53	80.74	3.02	8.83	6.81	7,926	.38	74.69	16.10	do	do	
239	W. Va. 14	Loup Creek	B.	1.56	1.06	5.15	80.73	8.12	2.38	7.01	8,090	2.05	64.57	30.00	do	Pottsville	Do.
239a	Ark. 3174	Paris	Sa.	1.49	2.85	3.87	80.48	2.04	9.27	7.11	7,824	.59	75.12	15.02	do	"Coal Meas."	
239b	Pa. "L"	Johnstown	Sb.	1.27	2.29	4.04	81.10	2.99	8.31	7.18	7,934	.64	76.38	14.67	do	do	L. Kittanning coal.
240	W. Va. 7	Sun	Sb.	1.05	1.20	4.38	82.41	5.87	5.09	7.52	8,254	.76	73.61	20.54	do	Pottsville	Run of mine, Sewell coal.
241	Md. 2	Frostburg	Sb.	1.49	.86	4.54	82.39	3.43	7.29	7.68	8,086	.74	73.83	18.14	do	"Coal Meas."	Pittsburg coal.
242	Ind. T. 9	Panama district	Sa.	1.68	1.24	4.35	82.06	2.26	8.41	7.69	7,948	.64	76.66	14.29	do	do	
242a	Ala. 3770	Sydenton	B.	1.55	.49	5.34	82.09	6.69	3.84	7.79	8,180	1.28	60.32	34.56	do	Pottsville	Wadsworth coal.
243	Va. 3	Coeburn	B.	1.63	.68	5.04	82.16	5.91	4.58	7.83	8,220	.87	62.19	32.36	do	do	Screened.
244	Pa. 8	Ehrenfield	Sb.	1.29	.97	4.37	83.11	3.43	6.83	8.10	8,170	.63	75.22	17.32	do	"Coal Meas."	Run of mine.
245	W. Va. 13	Page	B.	1.36	.91	5.15	82.65	5.91	4.01	8.32	8,234	1.17	62.95	31.87	do	Pottsville	Do.
246	W. Va. 12A	Big Sandy	Sb.	1.34	.69	4.36	83.63	3.03	6.95	8.38	8,185	.62	74.38	18.05	do	do	Do.
247	W. Va. 12	do	Sb.	1.33	.85	5.06	83.18	3.36	6.22	8.68	8,300	1.93			do	do	Briquettes.
248	W. Va. 6	Rush Run	Sb.	1.70	.66	4.70	83.62	4.23	5.09	8.97	8,301	.64	72.53	21.74	do	do	Run of mine.
249	W. Va. 19	McDonald	Sb.	1.60	.91	4.66	83.56	4.13	5.13	9.01	8,203	.68	70.91	23.28	do	do	Run of mine, Sewell coal.
250	W. Va. 10	Mora	Sb.	1.07	.57	4.58	85.91	3.24	4.63	10.91	8,439	.65	75.92	18.80	do	do	Pocahontas; prospect.

ARRANGEMENT OF ANALYSES.

It must be borne in mind that the analyses in this table are arranged according to the numerical sequence of the C:(O + ash) ratios of the samples. The calorific values determined directly from the same air-dried samples by the Mahler bomb calorimeter are set down in the column adjoining that of the ratios. Most of the calorific determinations were made in duplicate.

It will be remembered that in the ultimate analyses of air-dried samples, such as are here considered, the highly variable remaining moisture is included in the percentages of hydrogen and oxygen. Therefore in many cases the greater part of the oxygen of the analysis belongs to the retained moisture. The amount of moisture, as set down to the right of the calories column in the table, varies from 26.64 (No. 3, N. Dak., 3) to 0.34 (No. 237, Pa., 15). The fixed carbon and "volatile combustible matter" ascertained from the proximate analyses, also on the air-dried basis, are placed next beyond the moisture column. It will be seen that the percentages of ash range from 29.33 (No. 21, Mexico) to 2.38 (No. 239, W. Va., 14); and of oxygen from 38.57 (No. 2b, Wyo., 3694[a]) to 1.82 (No. 237, Pa., 15). The arrangement of coals so widely varying in these two respects purely on the basis of the numerical sequence of the C:(O + ash) ratios results in a mingling of fuels of very different kinds, characters, and ages, even bringing low-grade subbituminous coals (black lignites) into incongruous juxtaposition with Paleozoic coals of advanced devolatilization, the high oxygen of the former being balanced by the high ash of the latter.

FUELS HIGH IN OXYGEN OR ASH.

To show by specific illustrations the relative importance of oxygen and ash as indicated by the calorimetric tests, a few of the more conspicuous examples may be cited from Table 1: No. 8 (N. Dak., 1), from the Tertiary, has oxygen 27.15 and ash 12.24, the ratio of the carbon to them being 1.31; while No. 10 (Ind. T., 5), from the "Coal Measures," has oxygen 12.40 and ash 25.75, the ratio of carbon being 1.37. In these two analyses the oxygen and ash are contrastingly paired. The difference between the calorific values of the two coals is not far from the value corresponding to the difference between the two ratios, as will be shown later. No. 25, a Fort Union coal, at Monarch, Wyo., shows oxygen 28.99 and ash 4.79; while in No. 27, from Ozone, Tenn., the percentages are nearly reversed, oxygen being 4.90 and ash 28.53. The difference between the calorific values of

[a] The abnormally high oxygen of this Wyoming coal is the result of weathering. For an oxygen content nearer normal, see No. 5 (N. Dak., 2B), with 35.86; or No. 25 (Wyo., 1), with 28.99. That several of the lignites show more oxygen than the peats is due to the lesser moisture in the peat samples.

these two coals accords within 1 per cent with the value corresponding to the difference in their C:(O + ash) ratios. Again, No. 30, a bony layer high in ash in the Pocahontas (lower Pottsville) bed, at Gary, W. Va., and No. 32, a Laramie coal, at Lafayette, Colo., are nearly paired, the oxygen being 3.97 and 24.95, respectively, and the ash 28.77 and 6.32; neither of the calorific efficiencies differs 0.75 per cent from the calorific values corresponding to the carbon ratios. A still closer agreement with No. 32 is presented by No. 35, from Bonanza, Ark.; the fixed carbon in pure coal of the latter is 78.97, while that of No. 32 is but 53.69. The Paisley, Ill. (No. 42), and the Sprague, Mo. (No. 43), coals have oxygen contents of 16.1 and 8.46, respectively, their ash being 13.10 and 20.38; as compared with the calorific values corresponding to the respective ratios,[a] 2.06 and 2.08, the former has a deficiency of 36 calories, the latter an excess of 25. The agreement of No. 41 (Hanna, Wyo.) with the coals just cited is equally close in spite of its low ash, the ascertained calories being but 14 less than the number corresponding to its ratio, 2.04. An almost equal agreement in calorific values is shown in the contrasting anaylses, No. 64, from the Upper Cretaceous, at Gallup, N. Mex., and No. 65, from the "Coal Measures," at Yale, Kans.,[b] in which the oxygen is 21.14 and 5.13 and the ash 7.10 and 21.82, respectively. The error is not much greater between No. 100, from the Upper Cretaceous, at Van Houten, N. Mex., and No. 101, from the Carboniferous, at Dugger, Ind., in both of which the oxygen, at 9 and 15.76, is balanced by ash, 15.74 and 8.48.

FUELS OF LOWER ASH AND OXYGEN.

Passing on to coals of better quality, similar comparisons may be made between 119, 120, and 121, in which there is marked alternation in the amounts of these impurities, though the total difference in the efficiency is less than 20 calories. A greater contrast in age and character of the samples is found in No. 140, from the basal Mississippian ("Lower Carboniferous"), at Blacksburg, Va., and No. 144, from the Upper Cretaceous, at Rock Springs, Wyo. In the former the proportions are oxygen 4.02, ash 18.80; in the latter, oxygen 18.32 and ash 3.63. The Virginia coal is semianthracite, with a fixed carbon in pure coal of 86.89; the Wyoming is a subbituminous coal, having a fixed carbon of but 57.19. These have efficiencies, the first 33 and the other 30 calories less than the values corresponding to their respective ratios, 3.16 and 3.20. The efficiencies of No. 153, from the Indiana coal field, and No. 155, from the Ten-

[a] For calorific values corresponding to the ratio means, and for percentage ratios of volatile carbon, fixed carbon, available hydrogen, etc., see the same numbers in Table 2 (pp. 26-33).

[b] Unusually high available hydrogen compensated by very high sulphur.

nessee Pottsville, appear to conform very nearly to the means corresponding to the ratios, although the coals offer marked alternation in oxygen and ash. The Huntington, Ark., coal (No. 182) has a fixed carbon (in pure coal) of 79.25, and a Mesaverde coal, at Price, Utah (No. 184), but 52.68. The oxygen and ash nearly reciprocate at 4.70 and 12.88 against 12.21 and 5.06, the ratios being 4.30 and 4.35, respectively. The Huntington coal appears to have a deficiency of 60 calories, while the Utah coal has an equal number in surplus, the variance in either case being not more than 0.8 per cent of the calorific value.

Not to weary the reader with the details of further illustrations, a few additional comparisons are suggested as follows: Nos. 185 and 186; 193, 194, and 195; 199 and 200; 216 and 218; also Nos. 165 and 167; 131 and 132; 94 and 95; 39 and 40.

The more conspicuous contrasts noted in so many of these analyses naturally involve great differences in the kind and stage of development or maturity of the compared coals, whose proximate association in the table is due to the sequence of the ratios. The regularity of the coals with similar analyses, though from different regions or of different kinds, is well illustrated by Nos. 60 to 63; 91 and 92; 145 and 146; 173 and 174; and 220 to 223.

RELATION TO CALORIFIC VALUE.

However conspicuous or striking the contrasts offered by the examples specially cited above, the essential and most important evidence for the approximately equivalent negative values of oxygen and ash lies in the relatively close conformity, throughout the whole series, of the ascertained calorific values to the C:(O+ash) ratios; so that not only do coals having the same ratio closely approach the same efficiency values, but also the latter arrange themselves mainly in accordance with the sequence of the ratios. This may readily be noted in the series 25–50; 60–70; 87–125; 139–145; 164–176a; 182–201; 211a–226; and 241–250.

It must not be forgotten that in this treatment the hydrogen, sulphur, and nitrogen are assumed to be constant and therefore negligible; also that the oxygen of the analyses includes the oxygen of moisture as well as that really of the coal—that is, presumably in hydrocarbon combination.

The nearness to equality in the negative values of oxygen and ash is indicated fairly distinctly in Table 1. In a later section it will become more distinct, in connection with the discussion of the limits of variation from the ratio means, and the effect of the neglected "constants" as a cause of variance from a strict sequence in the calorific values.

CURVE PLATTED FROM C:(O+ASH) RATIOS AND EFFICIENCIES.

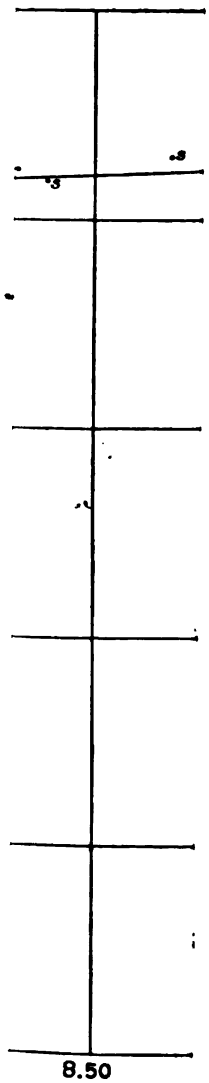
DETERMINATION OF CURVE.

In order to ascertain the mean calorific values corresponding to the various ratios, the efficiencies of all the coals in the tables have been platted in Plate I. The horizontal component is the C:(O + ash) ratio; the vertical is the heat value shown in the calorimeter tests. As thus platted the efficiencies are seen to describe a very clear and narrowly defined curve. The line in the figure is arbitrarily drawn to conform to the trend of this curve. Before proceeding, it may be remarked that the lower end of the curve is provisionally left dotted on account of the small number of wholly satisfactory analyses of the lowest grade coals, many samples having been more or less affected by exposure to the air. Also at the upper end additional analyses are needed for its more exact determination.

Considering that the hydrogen, sulphur, and nitrogen contents are here absolutely ignored and treated as negligible constants, the comparative proximity and regularity in the distribution of the efficiencies along the course of the curve is certainly remarkable. This regularity is explained (see p. 44) as due to the dominant control of the carbon, on the one hand, balanced by the chief impurities, oxygen and ash, on the other, in determining the calorific efficiencies of the ordinary types of the fuels, the hydrogen being either relatively stationary or, when in excess, more or less completely counteracted by relatively high sulphur, nitrogen, or unusually high ash, which may be slightly more deleterious than the oxygen. By referring to Table 1 it will be observed that the instances of wider departure from the curve are largely confined either to the weathered samples or to approaching anthracitization. The curve is particularly interesting because it is adjusted to a miscellaneous collection of coals of all grades, ages, and localities. It is not improbable that slight readjustments or special curves will be required for special groups of coals, like the cannels, or to suit the peculiarities of the coals of a given area.

DETAILED STUDY OF A CURVE SEGMENT.

The relative values of oxygen and ash and the approximation of the curve are diagrammatically expressed in Plate II, which shows on a large scale a section of the curve, embracing Nos. 25–50 of Table 1. Several of the intercalated analyses of samples, in some instances weathered, collected by the field geologists and recently published in U. S. Geol. Survey Bulletin 316, are here omitted. All fuels tested by the Survey are, however, included. The samples represent coals in Wyoming, Montana, Illinois, Tennessee, Missouri, West Virginia, Colorado, New Mexico, Arkansas, Iowa, and Washington. For description of the kind and age of each coal the reader is referred


8.50

CURVE PLATTED FROM C:(O+ASH) RATIOS AND EFFICIENCIES.

DETERMINATION OF CURVE.

In order to ascertain the mean calorific values corresponding to the various ratios, the efficiencies of all the coals in the tables have been platted in Plate I. The horizontal component is the C:(O + ash) ratio; the vertical is the heat value shown in the calorimeter tests. As thus platted the efficiencies are seen to describe a very clear and narrowly defined curve. The line in the figure is arbitrarily drawn to conform to the trend of this curve. Before proceeding, it may be remarked that the lower end of the curve is provisionally left dotted on account of the small number of wholly satisfactory analyses of the lowest grade coals, many samples having been more or less affected by exposure to the air. Also at the upper end additional analyses are needed for its more exact determination.

Considering that the hydrogen, sulphur, and nitrogen contents are here absolutely ignored and treated as negligible constants, the comparative proximity and regularity in the distribution of the efficiencies along the course of the curve is certainly remarkable. This regularity is explained (see p. 44) as due to the dominant control of the carbon, on the one hand, balanced by the chief impurities, oxygen and ash, on the other, in determining the calorific efficiencies of the ordinary types of the fuels, the hydrogen being either relatively stationary or, when in excess, more or less completely counteracted by relatively high sulphur, nitrogen, or unusually high ash, which may be slightly more deleterious than the oxygen. By referring to Table 1 it will be observed that the instances of wider departure from the curve are largely confined either to the weathered samples or to approaching anthracitization. The curve is particularly interesting because it is adjusted to a miscellaneous collection of coals of all grades, ages, and localities. It is not improbable that slight readjustments or special curves will be required for special groups of coals, like the cannels, or to suit the peculiarities of the coals of a given area.

DETAILED STUDY OF A CURVE SEGMENT.

The relative values of oxygen and ash and the approximation of the curve are diagrammatically expressed in Plate II, which shows on a large scale a section of the curve, embracing Nos. 25–50 of Table 1. Several of the intercalated analyses of samples, in some instances weathered, collected by the field geologists and recently published in U. S. Geol. Survey Bulletin 316, are here omitted. All fuels tested by the Survey are, however, included. The samples represent coals in Wyoming, Montana, Illinois, Tennessee, Missouri, West Virginia, Colorado, New Mexico, Arkansas, Iowa, and Washington. For description of the kind and age of each coal the reader is referred

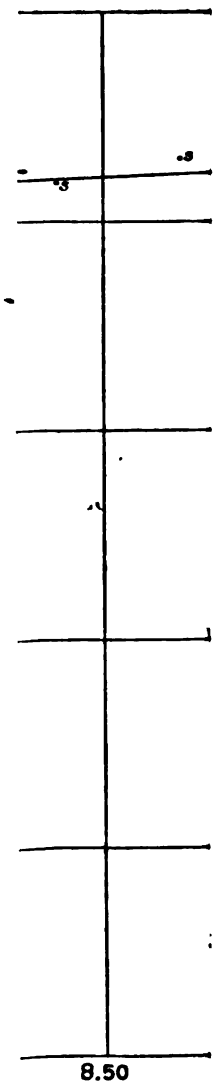

8.50

TABLE 1.—*Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C: (O+ash) ratio of each coal*—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	C / O+ash	Calories.	Moisture.	Fixed carbon.	Volatile matter.	Age.	Formation.	Remarks.
164	Tenn. 8A	Clifty	B.	1.17	4.45	4.97	70.45	5.50	13.64	3.68	7,179	1.05	51.26	34.05	Carboniferous.	Pottsville	Lump.
165	Ill. 34A	Harrisburg	B.	1.53	2.51	4.96	71.55	10.55	8.90	3.68	7,324	2.13	53.36	35.61	do	"Coal Meas."	Screenings.
166	Ala. 4	Belle Ellen	B.	1.25	1.14	4.89	73.09	5.96	13.67	3.72	7,287	.98	55.13	30.22	do	Pottsville	Run of mine.
166a	Colo. 3587	Book Cliffs field	B.	1.65	1.08	5.64	72.46	13.12	6.05	3.77	a7,207	4.17	52.20	37.58	Cretaceous	Mesaverde	Country bank.
167	Ohio 12B	Bellaire	B.	1.25	3.70	5.07	71.13	8.75	10.10	3.77	7,280	1.69	50.10	38.11	Carboniferous.	"Coal Meas."	
168	Ohio 10	Mineral City	B.	1.32	3.00	5.55	71.28	11.14	7.71	3.78	7,368	2.24	48.55	41.50	do	do	Lump.
169	Pa. 6	East Millsboro	B.	1.27	1.98	4.67	72.87	6.43	12.78	3.78	7,301	1.27	53.52	32.43	do	do	Run of mine.
170	Ill. 11C	Carterville	B.	1.43	1.76	4.99	72.80	10.84	8.18	3.82	7,263	2.36	54.84	34.62	do	do	
171	Ohio 9A	Clarion	B.	1.22	3.25	4.67	72.07	10.23	8.56	3.83	7,331	2.47	50.89	38.08	do	do	Lump.
171a	Colo. 3338	Newcastle	B.	1.76	.54	5.05	73.45	14.22	4.98	3.83	7,429	2.73	53.60	38.69	Cretaceous	Mesaverde	Mine sample.
171b	Colo. 3585	Book Cliffs field	B.	1.63	1.37	5.52	72.62	13.53	5.33	3.85	7,182	4.78	52.69	37.20	do	do	Do.
171c	Colo. 3332	Newcastle	B.	1.45	.42	5.21	73.98	13.53	5.41	3.91	7,364	3.19	55.49	35.91	do	do	Do.
172	Ohio 12A	Bellaire	B.	1.23	4.07	5.03	71.44	8.60	9.63	3.92	7,343	1.58	48.44	40.35	Carboniferous.	"Coal Meas."	Run of mine.
173	Kans. 5	West Mineral	B.	1.09	3.86	4.96	71.90	7.40	10.79	3.95	7,333	1.84	54.97	32.40	do	do	Screened.
173a	Wyo. 3570	Oyster Ridge	B.	1.18	.48	5.10	74.41	14.36	4.47	3.95	7,336	3.84	55.47	36.06	Cretaceous	Benton	Prospect.
173b	Colo. 3939	Newcastle	B.	1.73	.52	5.17	73.87	13.62	5.09	3.95	7,441	2.90	53.35	38.66	do	Mesaverde	Mine sample.
174	Tenn. 4	Oliver Springs	B.	1.03	1.03	5.13	73.62	8.58	10.00	3.96	7,333	1.77	54.32	33.91	Carboniferous.	Pottsville	Run of mine.
174a	Colo. 4036	North of Sunlight	B.	1.78	.53	5.49	73.65	16.61	1.94	3.97	7,465	4.18	54.63	39.25	Cretaceous	Mesaverde	Mine sample.
175	W. Va. 22B	Hernshaw	B.	1.18	1.04	5.06	74.16	8.47	10.09	3.99	7,344	1.74	53.80	34.37	Carboniferous.	Pottsville?	Run of mine.
175a	Colo. 4225	Near Mancos	B.	1.50	1.03	5.69	73.73	12.18	5.87	4.08	a7,316	3.51	51.12	39.50	Cretaceous	Mesaverde	Shallow mine.
176	Pa. 17	White	B.	1.44	1.56	4.83	74.06	5.80	12.31	4.08	7,448	1.09	57.87	28.71	Carboniferous.	"Coal Meas."	Run of mine.
176a	Colo. 7573	Hesperus	B.	1.40	.66	5.32	74.41	12.39	5.82	4.08	7,461	3.33	53.77	37.08	Cretaceous	Mesaverde	Mine sample.
177	W. Va. 25	Spring Hill	B.	1.43	.66	5.02	74.61	10.89	7.39	4.08	7,608	1.95	54.42	36.24	Carboniferous.	"Coal Meas."	Lump.
178	Ohio 4	Crow Hollow	B.	1.33	3.52	5.06	72.68	8.16	9.25	4.17	7,365	2.16	50.61	37.98	do	do	Screened.
179	Ark. 8	Spadra	Sa.	.53	2.14	3.44	75.77	3.47	14.65	4.18	7,244	.83	73.55	10.97	do	do	Stove coal.
179a	Colo. 4048	Sunlight	B.	1.86	.96	5.36	74.10	14.72	3.00	4.18	7,564	3.10	55.32	38.58	Cretaceous	Mesaverde	"D" bed.
180	Ky. 8	Sturgis	B.	1.23	1.22	4.87	74.99	9.51	8.18	4.24	7,598	2.33	57.48	32.01	Carboniferous.	"Coal Meas."	Run of mine.
181	Ark. 12	(?)	Sb.	1.38	1.68	3.78	75.49	4.15	13.52	4.27	7,282	1.22	68.58	16.68	do	do	Slack.
182	Ark. 1	Huntington	Sb.	1.47	1.27	4.00	75.68	4.70	12.88	4.30	7,450	1.17	68.12	17.83	do	do	
183	Ohio 5	Rush Run	B.	1.45	1.76	5.06	74.44	9.81	7.48	4.31	7,501	1.99	54.13	36.40	do	do	Screened.
184	Utah 1	Price	B.	1.43	.57	5.55	75.18	12.21	5.06	4.35	7,595	2.34	48.92	43.68	Cretaceous	Mesaverde	
185	Tenn. 5	Petros	B.	1.69	3.38	4.97	73.23	6.53	10.20	4.37	7,456	1.35	53.32	35.13	Carboniferous.	Pottsville	Run of mine.
186	Tenn. 3	Gatliff	B.	1.78	1.02	5.31	74.80	9.81	7.28	4.38	7,489	2.25	54.79	35.68	do	do	Do.
187	Ohio 6	Neffs	B.	1.17	3.47	5.16	73.58	7.76	8.87	4.42	7,425	1.47	51.45	38.21	do	"Coal Meas."	Do.
188	Ind. T. 2C	Hartshorne	B.	1.88	1.25	5.03	74.50	8.87	8.87	4.45	7,505	1.43	53.08	36.62	do	do	Lump.
189	Pa. 22	Huff	B.	1.58	1.03	4.77	75.69	6.44	10.49	4.47	7,632	.91	59.57	29.03	do	do	Run of mine.
190	Md. 1	Georges Creek	Sb.	1.32	1.51	3.88	76.28	3.09	13.32	4.48	7,409	.94	69.40	16.34	do	do	
191	Pa. 12	Acheson	B.	1.46	2.21	4.76	74.89	7.36	9.32	4.49	7,621	1.27	58.64	30.77	do	do	Do.
192	W. Va. 22A	Hernshaw	B.	1.22	.85	5.05	76.01	8.89	7.98	4.50	7,645	1.45	56.40	34.17	do	Pottsville	Screenings.
193	Pa. 7	Ligonier	B.	1.55	2.15	4.51	75.19	3.72	12.88	4.52	7,549	.92	64.90	21.30	do	"Coal Meas."	Run of mine.

194	Tenn. 9C	Coalmont	B.	1.28	.67	4.83	76.37	7.27	9.58	4.54	7,563	1.43	59.26	29.73	do	Pottsville	Slack.
195	Ark. 3	Jenny Lind	Sb.	1.55	1.30	4.07	76.37	4.91	11.80	4.57	7,586	.80	67.65	19.75	do	"Coal Meas."	
196	Pa. 21	Connelsville	B.	1.57	.90	4.63	76.34	7.47	9.09	4.61	7,751	.97	60.85	29.09	do	do	Run of mine.
197	Pa. 4	Greensburg	B.	1.46	1.29	4.82	76.00	5.78	10.64	4.62	7,616	.97	57.44	30.95	do	do	Lump.
198	W. Va. 3	Richard	B.	1.44	1.07	4.91	76.12	6.09	10.37	4.62	7,631	1.00	58.38	30.25	do	do	Run of mine.
199	W. Va. 23B	Monarch	B.	1.19	1.36	5.04	76.02	8.24	8.15	4.64	7,661	1.46	55.47	34.92	do	Pottsville	Slack.
200	W. Va. 5	Coalton	B.	1.48	.99	4.78	76.36	6.21	10.18	4.65	7,652	.65	59.97	29.20	do	"Coal Meas."	Coarse coal.
201	W. Va. 16	Monongah	B.	1.53	1.26	4.80	76.09	7.56	8.76	4.66	7,609	1.22	56.96	33.06	do	do	Screenings.
202	Pa. 19	Herminie	B.	1.42	1.08	4.92	76.25	7.76	8.57	4.67	7,752	1.01	57.85	32.57	do	do	Run of mine.
203	Mo. 4	Barnet	B.	.75	5.55	5.77	72.45	10.25	5.23	4.68	7,516	5.39	44.47	44.91	do	do	Do.
204	Ky. 1B	Straight Creek	B.	1.73	1.16	5.06	75.89	7.62	8.54	4.69	7,623	1.57	55.14	34.75	do	Pottsville	
205	W. Va. 2	Clarksburg	B.	1.37	3.50	5.09	74.44	7.70	7.90	4.70	7,700	1.46	50.50	40.14	do	"Coal Meas."	Do.
206	Ark. 7A	Midland	Sb.	1.32	2.12	3.99	76.37	3.91	12.29	4.71	7,413	.60	70.00	17.11	do	do	Slack.
207	Tenn. 2	Gatliff	B.	1.81	1.01	5.20	75.97	8.98	7.03	4.74	7,630	1.95	54.05	36.97	do	Pottsville	Run of mine.
208	W. Va. 4B	Bretz	B.	1.60	1.10	4.52	76.72	5.68	10.38	4.77	7,626	1.35	60.88	27.39	do	"Coal Meas."	Do.
208a	Wyo. 4303	Willow Creek	B.	1.31	.94	5.04	76.84	12.64	3.23	4.84	7,812	1.99	57.53	37.18	Cretaceous	Benton	Prospect.
208b	Colo. 4010	Gulch	B.	1.56	.45	5.16	77.05	9.46	6.32	4.88	7,860	1.21	57.30	35.17	do	Mesaverde	Mine sample.
208c	Ala. 3499	Lovick	B.	1.69	1.10	4.89	76.64	7.20	8.48	4.88	7,613	1.19	59.43	30.90	Carboniferous	Pottsville	
209	W. Va. 23A	Monarch	B.	1.45	1.24	5.13	76.57	7.90	7.71	4.90	7,643	1.58	55.50	35.21	do	do	Run of mine.
210	Va. 6	Richlands	B.	1.33	1.27	4.44	77.21	5.45	10.30	4.90	7,757	.65	64.77	24.28	do	do	Do.
210a	Ala. 3745	Coalmont	B.	1.13	.88	5.01	77.40	9.28	6.30	4.96	7,764	1.67	59.11	32.92	do	do	Mine sample.
211	Ark. 5	Coal Hill	Sa.	1.39	2.01	3.74	77.29	3.36	12.21	4.96	7,443	1.28	73.69	12.82	do	"Coal Meas."	
211a	Colo. 3552	Near Durango	B.	1.50	1.38	5.29	76.63	9.89	5.31	5.04	[b]7,676	2.07	54.22	38.40	Cretaceous	Mesaverde	Weathered.
212	Pa. 9	Kimmelton	Sb.	1.29	2.09	4.00	77.42	3.58	11.63	5.09	7,657	.50	70.12	17.75	Carboniferous	"Coal Meas."	Run of mine.
213	W. Va. 11	Zenith	Sb.	1.04	.53	4.03	79.12	3.78	11.50	5.17	7,761	.80	70.80	16.90	do	Pottsville	Run of mine, Pocahontas.
214	Pa. 11	Charleroi	B.	1.45	1.19	5.09	77.32	7.62	7.33	5.17	7,699	1.36	57.03	34.28	do	"Coal Meas."	Run of mine, Pittsburg.
215	W. Va. 15	Clarksburg	B.	1.44	2.56	5.03	76.52	5.82	8.63	5.29	7,743	1.12	52.60	37.65	do	do	Do.
215a	Wyo. 4299	Willow Creek	B.	.85	.71	5.59	78.19	11.18	3.48	5.33	7,716	2.37	57.33	36.79	Cretaceous	Benton	Tunnel.
216	W. Va. 14	Bretz	B.	1.50	.90	4.85	78.21	6.11	8.43	5.37	7,855	.98	61.87	28.72	Carboniferous	"Coal Meas."	Run of mine.
216a	Ala. 3771	Acton basin	B.	1.53	.24	5.15	78.67	8.46	5.75	5.53	7,791	1.86	58.75	33.64	do	Pottsville	Helena coal.
217	Va. 4	Darby	B.	1.35	.81	5.13	78.56	9.73	4.42	5.55	7,902	2.40	55.54	37.64	do	do	Screened.
218	Va. 2B	Crab Orchard	B.	1.45	.94	5.08	78.51	8.33	5.69	5.59	7,890	1.48	57.02	35.81	do	do	Run of mine.
219	W. Va. 1	Kingmont	B.	1.55	.90	5.26	78.31	7.61	6.37	5.60	7,869	1.35	55.36	36.92	do	"Coal Meas."	Do.
220	Pa. 10	Bruce	B.	1.59	1.28	5.14	78.16	7.58	6.25	5.64	7,877	1.33	57.04	35.38	do	do	Nut.
221	Va. 1	Crab Orchard	B.	1.27	1.23	5.17	78.47	9.01	4.85	5.66	7,870	1.70	57.66	35.79	do	Pottsville	Run of mine.
222	W. Va. 20	Acme	B.	1.37	1.41	5.04	78.39	5.59	8.20	5.68	7,812	.74	58.17	32.89	do	do	Do.
223	W. Va. 8	Ansted	B.	1.38	.92	5.16	78.75	6.43	7.36	5.71	7,863	1.60	58.92	32.12	do	do	Do.
224	Ky. 6	Miller Creek	Sp.	1.48	.58	5.35	78.94	10.83	2.82	5.78	7,807	2.99	56.88	37.31	do	do	"Splint."
225	W. Va. 17	Near Bretz	B.	1.41	1.49	4.51	78.95	5.31	8.33	5.78	7,903	1.00	62.68	27.99	do	"Coal Meas."	Prospect.
226	Pa. 5	Ellsworth	B.	1.55	.89	5.20	78.78	7.47	6.11	5.80	7,864	1.47	57.59	34.83	do	do	Screened, Pittsburg.
227	Pa. 16	Hastings	Sb.	1.33	1.65	4.46	79.00	5.37	8.19	5.83	7,812	.36	68.78	22.67	do	do	Run of mine.
227a	Ala. 3769	Acton basin	B.	1.25	1.10	5.01	79.16	8.83	4.65	5.87	7,964	1.62	59.87	33.86	do	Pottsville	Helena coal.
228	Pa. 20	Seward	Sb.	1.16	2.96	4.55	78.23	2.17	10.93	5.90	7,692	.42	72.17	16.48	do	"Coal Meas."	Run of mine.
229	Ky. 1	Straight Creek	B.	1.85	1.24	5.36	78.31	8.80	4.44	5.91	7,955	1.92	57.08	36.56	do	Pottsville	Do.
230	Pa. 15B	Wehrum	Sb.	1.18	4.06	4.29	77.52	2.40	10.55	5.98	7,781	.48	70.49	18.48	do	"Coal Meas."	Do.
231	W. Va. 18	Glen Alum	B.	1.45	.68	4.91	79.65	7.39	5.92	5.98	7,963	1.28	59.03	33.77	do	Pottsville	Do.
231a	Ala. 3744	Fallston	Sb.	1.33	.67	5.26	79.50	10.03	3.21	6.01	8,115	1.52	60.68	34.59	do	do	Buck bed.
231b	Colo. 4047	Coal basin	B.	1.83	.52	4.65	79.77	4.59	8.64	6.03	7,977	.76	69.07	21.53	Cretaceous	Mesaverde	Run of mine.

[a] From shallow mine or country bank.

[b] Coals more or less weathered.

TABLE 1.—*Ultimate analyses of 319 American coals, "air-dried" basis, from the chemical laboratory of the U. S. Geological Survey, with calorific value and C : (O+ash) ratio of each coal*—Continued.

No.	Designation of coal.	Locality.	Kind.	N.	S.	H.	C.	O.	Ash.	$\frac{C}{O+ash}$	Calories.	Moisture.	Fixed carbon.	Volatile matter.	Age.	Formation.	Remarks.
232	W. Va. 9	Powellton	B.	1.63	.80	5.04	79.35	6.39	6.79	6.03	7,984	1.01	62.67	29.53	Carboniferous.	Pottsville	Run of mine.
233	Ky. 5	Big Black Mountain.	B.	1.61	.69	4.99	79.67	9.23	3.81	6.10	7,958	1.60	58.56	36.03	do	do	"Splint;" prospect.
234	W. Va. 21	Winifrede	B.	1.52	1.35	5.21	79.15	7.83	4.95	6.19	7,915	1.50	56.39	37.16	do	do	Run of mine, Winifrede coal.
235	Ala. 6	Dolomite	B.	1.45	.63	4.84	80.25	5.94	6.88	6.26	8,011	.85	65.47	26.80	do	do	Run of mine, Pratt coal.
236	Ark. 2	Bonanza	Sb.	1.40	1.90	4.13	80.03	3.20	9.34	6.38	7,756	.74	73.66	16.26	do	"Coal Meas."	
237	Pa. 15	Wehrum	Sb.	1.17	3.88	4.43	78.61	1.82	10.09	6.60	7,885	.34	71.45	18.12	do	do	Run of mine.
238	Pa. 18	Lloydell	Sb.	1.23	1.55	4.53	80.74	3.02	8.83	6.81	7,926	.38	74.69	16.10	do	do	
239	W. Va. 14	Loup Creek	B.	1.56	1.06	5.15	80.73	8.12	2.38	7.01	8,090	2.05	64.57	30.00	do	Pottsville	Do.
239a	Ark. 3174	Paris	Sa.	1.49	2.85	3.87	80.48	2.04	9.27	7.11	7,824	.59	75.12	15.02	do	"Coal Meas."	
239b	Pa. "L"	Johnstown	Sb.	1.27	2.29	4.04	81.10	2.99	8.31	7.18	7,934	.64	76.38	14.67	do	do	L. Kittanning coal.
240	W. Va. 7	Sun	Sb.	1.05	1.20	4.38	82.41	5.87	5.09	7.52	8,254	.76	73.61	20.54	do	Pottsville	Run of mine, Sewell coal.
241	Md. 2	Frostburg	Sb.	1.49	.86	4.54	82.39	3.43	7.29	7.68	8,086	.74	73.83	18.14	do	"Coal Meas."	Pittsburg coal.
242	Ind. T. 9	Panama district	Sa.	1.68	1.24	4.35	82.06	2.26	8.41	7.69	7,948	.64	76.66	14.29	do	do	
242a	Ala. 3770	Sydenton	B.	1.55	.49	5.34	82.09	6.69	3.84	7.79	8,180	1.28	60.32	34.56	do	Pottsville	Wadsworth coal.
243	Va. 3	Coeburn	B.	1.63	.68	5.04	82.16	5.91	4.58	7.83	8,220	.87	62.19	32.36	do	do	Screened.
244	Pa. 8	Ehrenfield	Sb.	1.29	.97	4.37	83.11	3.43	6.83	8.10	8,170	.63	75.22	17.32	do	"Coal Meas."	Run of mine.
245	W. Va. 13	Page	B.	1.36	.91	5.15	82.65	5.91	4.01	8.32	8,234	1.17	62.95	31.87	do	Pottsville	Do.
246	W. Va. 12A	Big Sandy	Sb.	1.34	.69	4.36	83.63	3.03	6.95	8.38	8,185	.62	74.38	18.05	do	do	Do.
247	W. Va. 12	do	Sb.	1.33	.85	5.06	83.18	3.36	6.22	8.68	8,300	1.93			do	do	Briquettes.
248	W. Va. 6	Rush Run	Sb.	1.70	.66	4.70	83.62	4.23	5.09	8.97	8,301	.64	72.53	21.74	do	do	Run of mine.
249	W. Va. 19	McDonald	Sb.	1.60	.91	4.66	83.56	4.13	5.13	9.01	8,203	.68	70.91	23.28	do	do	Run of mine, Sewell coal.
250	W. Va. 10	Mora	Sb.	1.07	.57	4.58	85.91	3.24	4.63	10.91	8,439	.65	75.92	18.80	do	do	Pocahontas; prospect.

ARRANGEMENT OF ANALYSES.

It must be borne in mind that the analyses in this table are arranged according to the numerical sequence of the C:(O + ash) ratios of the samples. The calorific values determined directly from the same air-dried samples by the Mahler bomb calorimeter are set down in the column adjoining that of the ratios. Most of the calorific determinations were made in duplicate.

It will be remembered that in the ultimate analyses of air-dried samples, such as are here considered, the highly variable remaining moisture is included in the percentages of hydrogen and oxygen. Therefore in many cases the greater part of the oxygen of the analysis belongs to the retained moisture. The amount of moisture, as set down to the right of the calories column in the table, varies from 26.64 (No. 3, N. Dak., 3) to 0.34 (No. 237, Pa., 15). The fixed carbon and "volatile combustible matter" ascertained from the proximate analyses, also on the air-dried basis, are placed next beyond the moisture column. It will be seen that the percentages of ash range from 29.33 (No. 21, Mexico) to 2.38 (No. 239, W. Va., 14); and of oxygen from 38.57 (No. 2b, Wyo., 3694[a]) to 1.82 (No. 237, Pa., 15). The arrangement of coals so widely varying in these two respects purely on the basis of the numerical sequence of the C:(O + ash) ratios results in a mingling of fuels of very different kinds, characters, and ages, even bringing low-grade subbituminous coals (black lignites) into incongruous juxtaposition with Paleozoic coals of advanced devolatilization, the high oxygen of the former being balanced by the high ash of the latter.

FUELS HIGH IN OXYGEN OR ASH.

To show by specific illustrations the relative importance of oxygen and ash as indicated by the calorimetric tests, a few of the more conspicuous examples may be cited from Table 1: No. 8 (N. Dak., 1), from the Tertiary, has oxygen 27.15 and ash 12.24, the ratio of the carbon to them being 1.31; while No. 10 (Ind. T., 5), from the "Coal Measures," has oxygen 12.40 and ash 25.75, the ratio of carbon being 1.37. In these two analyses the oxygen and ash are contrastingly paired. The difference between the calorific values of the two coals is not far from the value corresponding to the difference between the two ratios, as will be shown later. No. 25, a Fort Union coal, at Monarch, Wyo., shows oxygen 28.99 and ash 4.79; while in No. 27, from Ozone, Tenn., the percentages are nearly reversed, oxygen being 4.90 and ash 28.53. The difference between the calorific values of

[a] The abnormally high oxygen of this Wyoming coal is the result of weathering. For an oxygen content nearer normal, see No. 5 (N. Dak., 2B), with 35.86; or No. 25 (Wyo., 1), with 28.99. That several of the lignites show more oxygen than the peats is due to the lesser moisture in the peat samples.

TABLE 2.—*The coals of Table 1, showing moisture-free hydrogen and oxygen; fixed carbon in pure coal; hydrogen to oxygen, and volatile carbon to carbon ratios; "available" hydrogen; and variance from C:(O+ash) ratio and efficiency curve*—Continued.

No.	Designation of coal.	N.	S.	H (−H_2O).	C.	O (−H_2O).	Ash.	H_2O.*	C / O+ash	Calories.	Proximate. Fixed carbon.	Proximate. Volatile matter.	Fixed carbon in pure coal.	Vol. C / C	H / O	Variance from curve (calories).	Available H.
														Per cent.	*Per ct.*		
62a	Utah 4013	1.30	.47	4.14	64.88	15.56	8.53	5.12	2.26	6,293	53.21	33.14	61.62	17.99	26.6	− 30	2.20
63	Iowa 3	.93	6.83	4.43	60.62	7.14	15.53	4.52	2.27	6,309	38.99	40.96	48.77	35.68	62.0	− 25	3.54
64	N. Mex. 1	1.05	.64	4.52	64.34	11.49	7.10	10.86	2.28	6,353	46.90	35.14	57.16	27.10	39.3	+ 2	3.08
65	Kans. 2B	1.11	5.03	4.09	62.65	3.79	21.82	1.51	2.32	6,329	48.42	28.25	63.15	22.71	107.9	− 37	3.62
66	Ind. 14	.97	5.34	4.51	62.95	8.04	14.75	4.34	2.33	6,430	42.64	38.27	52.70	31.28	56.1	+ 45	3.50
66a	Colo. 3498	1.26	.76	4.40	64.95	14.03	7.42	7.18	2.33	6,446	46.50	38.90	54.45	28.41	31.4	+ 58	2.65
67	Ind. 13	.87	3.37	4.40	63.39	7.54	12.81	7.62	2.34	6,414	42.02	37.55	52.81	33.71	58.3	+ 14	3.46
68	Ind. 4	1.24	2.59	4.26	64.10	8.18	16.05	3.58	2.34	6,426	47.41	32.96	58.99	26.04	52.0	+ 26	3.24
69	Ill. 30	1.03	4.80	4.56	62.60	9.29	14.45	3.27	2.35	6,510	43.18	39.10	52.48	31.02	49.1	+105	3.40
70	Ill. 21	1.22	1.54	4.30	64.76	10.24	12.20	5.74	2.35	6,514	47.17	34.89	57.48	27.16	41.9	+109	3.02
71	Ill. 22B	1.00	4.90	4.29	62.99	8.40	16.36	2.06	2.36	6,376	44.81	36.77	59.43	28.86	51.1	− 32	3.24
72	Ind. T. 4	1.38	4.02	4.29	63.21	8.79	13.40	4.91	2.38	6,327	43.90	37.79	53.74	30.54	48.8	− 97	3.19
72a	Colo. 3545	1.47	.66	4.47	65.05	12.07	6.28	10.00	2.38	[a] 6,312	50.98	32.74	60.89	21.63	37.0	−112	2.96
73	Ill. 31	1.14	4.05	4.41	63.47	8.49	14.67	3.77	2.39	6,394	45.94	35.62	56.33	27.62	51.9	− 40	3.35
73a	Colo. 3490	1.13	.89	4.44	65.51	11.44	10.42	6.17	2.39	6,532	47.13	36.28	56.50	27.75	38.8	+ 95	3.01
73b	Mont. 4115	.92	2.43	3.92	65.17	9.37	14.49	3.70	2.40	6,348	52.68	29.13	64.39	19.16	41.8	− 95	2.75
73c	Wyo. 2283	1.03	.58	4.25	65.76	16.07	3.43	8.88	2.40	6,385	47.20	40.49	53.83	28.22	26.5	− 58	2.24
74	Ind. 2	1.25	4.60	4.42	62.97	7.01	13.51	6.24	2.41	6,410	42.76	37.49	53.28	32.09	63.0	− 40	3.54
75	Ind. 7	.94	3.85	4.21	63.70	8.33	11.61	7.36	2.41	6,446	46.80	34.23	57.76	26.53	50.5	− 4	3.17
75a	Colo. 3462	1.22	1.14	4.57	65.33	12.71	6.37	8.66	2.44	[a] 6,419	47.29	37.68	55.65	27.62	35.9	− 55	2.98
75b	Colo. 3704	1.40	.54	4.25	66.12	14.00	4.78	8.91	2.48	6,534	49.22	37.09	57.03	25.56	30.4	+ 25	2.50
76	Ill. 14	1.19	4.52	4.43	63.85	8.08	12.80	5.13	2.50	6,496	44.31	37.70	54.03	30.60	54.8	−105	2.42
77	Ohio 3	1.28	1.88	4.36	65.62	8.57	12.05	6.24	2.51	6,519	46.68	35.03	57.13	28.86	50.8	− 11	3.29
78	Ill. 12	1.14	3.61	4.33	64.85	7.87	13.43	4.77	2.54	6,548	48.34	33.46	59.10	25.46	55.0	− 5	3.35
79	Kans. 2	.94	6.40	4.31	63.14	4.71	18.27	2.23	2.54	6,600	47.63	31.87	59.91	24.56	91.5	+ 47	3.72
80	Ind. 6	1.19	4.63	4.49	64.22	6.25	13.31	5.91	2.58	6,555	42.71	38.07	52.87	33.49	71.8	− 25	3.71
81	Ill. 9A	1.04	4.43	4.63	64.49	8.62	11.80	4.99	2.59	6,538	43.99	39.22	52.86	31.79	53.7	− 52	3.55
81a	Ariz. 4112	1.28	.42	4.65	66.81	12.90	4.05	9.80	2.59	6,723	46.95	39.09	54.58	27.73	36.1	+133	3.04
82	Ill. 26	1.21	4.02	4.37	65.02	8.12	13.85	3.41	2.60	6,579	45.62	37.12	55.14	29.84	53.8	− 20	3.35
83	Wyo. 6	1.10	.55	4.85	66.95	14.29	3.52	8.68	2.61	[b] 6,456	46.49	41.31	52.83	30.56	33.9	−150	3.06
84	Ill. 19E	1.53	.54	3.95	67.48	10.31	10.92	5.27	2.61	6,625	52.58	31.23	62.74	22.08	38.3	+ 20	2.66
84a	Colo. 3703	1.12	.60	4.24	67.42	14.93	3.02	8.67	2.62	6,654	49.99	38.32	56.61	25.85	28.4	+ 40	2.37
85	Ala. 2B	1.52	1.14	4.21	67.35	8.65	14.84	2.29	2.63	6,660	51.64	31.23	62.31	23.33	48.6	+ 40	3.13
86	N. Mex. 3A	1.25	.74	4.67	67.54	7.31	17.01	1.48	2.63	6,742	48.80	32.71	59.87	27.75	63.9	+122	3.76
87	Ind. 16	1.13	4.50	4.50	64.82	7.88	12.49	4.68	2.64	6,623	44.24	38.59	53.41	31.75	57.1	− 4	3.52
88	Kans. 6	1.14	4.00	4.31	65.05	5.89	16.92	2.09	2.66	6,663	49.03	31.96	60.54	25.32	73.2	+ 20	3.57
89	Tenn. 9B	1.26	.78	4.56	67.76	5.09	19.47	1.03	2.66	6,693	52.89	26.01	66.53	21.95	89.6	+ 50	3.92
90	Mo. 5	1.02	5.68	4.50	64.52	7.20	15.37	1.71	2.69	6,614	44.95	37.97	54.21	30.33	62.5	− 35	3.60

91	Ind. 12	1.25	4.13	4.52	65.28	7.92	12.45	4.45	2.68	6,688	45.68	37.42	54.97	30.04	57.0	+ 30	3.53
92	Ohio 2	1.25	4.17	4.55	65.14	7.52	11.76	5.61	2.68	6,625	45.44	37.19	55.00	30.24	60.5	− 30	3.61
93	N. Mex. 3B	1.22	.86	4.44	69.00	7.67	16.41	1.40	2.68	6,823	48.98	33.21	59.59	27.97	57.8	+168	2.48
94	Ill. 23B	1.03	4.98	4.66	65.10	8.97	13.03	2.23	2.71	6,598	45.93	38.81	54.20	29.45	51.9	− 80	3.54
95	Ill. 19C	1.49	.54	4.43	67.91	8.19	11.43	6.61	2.72	6,596	52.23	30.33	63.26	23.09	54.1	− 88	3.41
96	Ill. 24A	1.10	5.83	4.46	64.86	8.32	11.57	4.36	2.72	6,575	47.43	36.64	56.42	26.87	53.6	−110	3.42
97	Ill. 3	1.43	1.77	4.26	67.30	7.69	11.59	5.96	2.74	6,724	52.16	30.29	63.26	22.50	55.6	+ 24	3.30
98	Ind. 5	1.16	4.60	4.49	65.44	7.38	11.72	5.21	2.75	6,700	44.65	38.42	53.75	31.77	60.8	− 6	3.57
99	Ill. 9B	1.09	4.40	4.69	65.57	8.74	11.48	4.03	2.75	6,717	44.18	40.31	52.29	32.62	53.6	+ 11	3.60
100	N. Mex. 3C	1.20	.65	4.60	68.66	7.78	15.74	1.37	2.77	6,855	49.23	33.66	59.39	28.30	59.1	+155	3.63
101	Ind. 11	1.44	1.47	4.28	67.63	8.21	8.48	8.49	2.79	6,806	48.16	34.87	58.00	28.79	52.1	+ 74	3.25
101a	Colo. 3550	1.26	.63	4.71	68.46	9.43	11.21	4.30	2.79	6,757	47.53	33.32	58.79	30.57	49.9	+ 25	3.53
102	Ind. 9	1.12	3.56	4.61	66.48	7.80	11.20	5.24	2.81	6,714	45.73	37.83	54.76	31.21	59.1	− 30	3.64
103	Ind. 18B	1.18	1.49	4.51	67.95	8.88	7.08	8.92	2.84	6,881	48.57	35.43	57.82	28.52	50.8	+115	3.40
104	Ill. 34B	1.38	2.96	4.37	67.29	8.35	12.73	2.92	2.84	6,883	51.25	33.10	60.76	23.84	52.3	+117	3.33
105	Ohio 1	1.17	4.85	4.79	65.70	7.96	12.57	2.96	2.84	6,727	44.18	40.29	52.30	32.75	60.4	− 35	3.60
106	Ill. 19	1.48	.57	4.14	67.05	8.55	9.82	6.39	2.86	6,697	54.46	29.33	65.00	29.13	48.4	− 80	3.67
107	Ind. 9B	1.19	3.53	4.79	66.79	8.48	12.05	3.17	2.86	6,811	45.81	38.97	54.03	31.41	56.5	+ 22	3.73
108	Ky. 4	1.28	4.67	4.25	66.50	6.17	14.59	2.54	2.88	6,830	46.79	36.08	56.46	29.63	68.8	+ 38	3.48
109	Ohio 9B	1.12	3.55	4.51	67.31	8.23	12.64	2.65	2.89	6,805	55.65	39.06	53.83	32.18	54.8	+ 8	3.48
110	Ill. 10	1.46	1.56	4.57	68.56	8.77	12.29	2.79	2.89	6,866	50.57	34.35	59.55	26.25	52.1	+ 69	3.47
110a	Wyo. 3891	1.38	.33	4.56	69.07	13.03	4.92	6.71	2.89	6,879	48.42	39.95	54.79	29.90	35.0	+ 82	2.93
111	Ky. 3	1.43	3.60	4.62	66.75	7.46	10.29	5.85	2.92	6,829	46.96	36.90	55.99	29.64	61.9	+ 11	3.69
112	Ill. 12B	1.02	2.60	4.36	68.30	8.22	11.54	3.97	2.93	6,756	51.43	33.06	60.87	24.70	53.1	− 60	3.33
112a	Wyo. 3509	1.79	.88	4.53	68.93	12.16	5.99	5.72	2.96	6,759	49.76	38.53	56.36	27.81	37.3	− 80	3.01
113	Mo. 6	1.08	6.34	4.46	65.71	6.64	13.28	2.49	2.96	6,785	45.44	38.79	53.95	30.85	67.1	− 55	3.63
114	Ala. 2	1.55	1.02	4.50	69.24	8.56	12.53	2.58	2.96	6,916	51.74	33.15	60.95	25.27	52.5	+ 76	3.43
115	Ind. T. 8	1.64	1.93	4.42	68.65	6.82	14.25	2.29	2.97	6,837	50.21	33.25	60.16	26.86	64.8	− 8	3.57
116	Ill. 12C	1.19	2.65	4.46	68.36	8.07	11.95	3.32	2.97	6,862	51.70	33.03	61.02	24.35	55.2	+ 17	3.45
117	Ind. 8	1.13	3.90	4.63	67.17	6.86	11.12	5.19	2.97	6,848	45.76	37.93	54.68	31.87	67.5	+ 3	3.77
118	N. Mex. 4B	1.53	.62	4.81	69.48	7.38	14.78	1.40	2.97	6,927	49.02	34.80	58.48	29.45	55.2	+ 82	3.89
119	Ill. 11B	1.37	2.62	4.52	68.25	7.60	12.38	3.25	2.99	6,901	51.19	33.18	60.68	25.00	59.4	+ 41	3.57
120	Ill. 18	1.09	4.28	4.89	66.91	8.73	9.74	4.36	2.99	6,914	45.63	40.27	53.13	31.80	56.0	+ 54	3.80
121	Ala. 5	1.33	1.46	4.26	69.64	5.25	16.82	1.24	3.00	6,920	55.74	26.20	68.02	19.96	81.1	+ 55	3.60
122	Ill. 13	1.55	1.62	4.47	69.00	8.48	10.49	3.89	3.00	6,829	51.94	33.18	61.02	24.73	52.7	− 35	3.41
123	Ark. 1B	1.46	1.14	3.77	70.25	3.27	19.26	.85	3.01	6,770	63.69	16.25	79.66	9.40	115.3	−100	3.36
124	Ill. 28C	1.25	1.36	4.33	69.54	8.30	10.29	4.93	3.02	6,849	54.11	30.77	63.76	22.19	52.2	− 30	3.29
125	Ind. T. 2B	1.72	1.88	4.35	69.15	6.43	15.03	1.44	3.04	6,915	49.49	34.04	59.25	28.43	67.6	+ 25	3.55
126	N. Mex. 4A	1.53	.62	4.84	69.86	7.67	13.77	1.71	3.04	7,034	49.29	35.23	58.32	29.44	63.1	+144	3.88
127	Ill. 12D	1.22	2.70	4.42	68.81	8.90	10.98	2.97	3.05	6,710	53.54	32.51	62.22	22.19	49.6	+ 12	3.31
128	Wash. 2	1.26	.38	4.87	70.26	8.93	12.42	1.88	3.05	7,084	48.73	36.97	56.88	30.64	54.5	+186	3.75
129	Ky. 7	1.32	3.71	4.43	67.80	7.33	9.77	5.64	3.06	6,863	48.26	36.33	57.05	28.82	60.4	− 40	3.51
130	Ky. 2	1.25	3.72	4.73	67.64	7.92	9.38	5.36	3.06	6,966	46.27	38.99	54.28	31.59	59.7	+ 63	3.74
131	Ohio 11	1.19	4.39	4.50	67.72	7.18	13.15	1.87	3.08	6,937	48.35	36.63	56.89	28.60	62.7	+ 19	3.61
132	Ind. 18A	1.38	1.69	4.56	67.08	7.80	7.20	8.29	3.08	6,898	48.28	36.23	57.12	30.11	68.7	− 17	3.59
133	Ky. 9A	1.24	3.25	4.81	68.01	8.01	9.29	5.35	3.08	6,953	49.05	36.27	57.49	27.88	60.0	+ 38	3.81
134	Ala. 3	1.15	.56	4.30	70.84	7.08	14.53	1.54	3.08	7,007	54.11	29.82	64.41	23.62	60.7	+ 92	3.42
134a	Colo. 3541	1.58	.87	4.51	69.83	11.47	6.11	5.33	3.09	6,978	51.49	36.77	58.34	26.26	39.3	+ 55	3.08

* Moisture (H_2O) is included as a separate percentage to conserve the "air-dried" basis of the analyses and calorific determinations.
[a] Coals more or less weathered.
[b] Car sample (in part).

TABLE 2.—*The coals of Table 1, showing moisture-free hydrogen and oxygen; fixed carbon in pure coal; hydrogen to oxygen, and volatile carbon to carbon ratios; "available" hydrogen; and variance from C : (O+ash) ratio and efficiency curve*—Continued.

No.	Designation of coal.	N.	S.	H−H_2O.	C.	O+H_2O.	Ash.	H_2O.*	C/(O+ash)	Calories.	Proximate. Fixed carbon.	Volatile matter.	Fixed carbon in pure coal.	Vol. C/C	H/O	Variance from curve (calories).	Available H.
														Per cent.	*Per ct.*		
135	Ky. 9B	1.39	3.10	4.64	68.35	8.11	10.50	3.91	3.09	6,985	51.49	34.10	60.15	24.67	57.2	+ 63	3.63
135a	Ill. 19D	1.56	.64	4.08	70.55	9.67	9.63	3.87	3.10	6,897	55.19	31.31	63.80	21.77	42.2	− 30	2.87
136	Ind. 15	1.56	1.00	4.56	69.89	8.09	8.97	4.93	3.11	6,979	50.82	35.28	59.03	27.29	56.7	+ 44	3.55
136a	Colo. 3640	1.20	.49	4.80	70.32	12.24	5.74	5.21	3.11	6,908	55.69	33.36	62.54	20.80	39.2	− 27	3.27
137	Ind. T. 3	1.50	3.67	4.47	68.18	7.45	11.28	3.46	3.12	6,927	47.82	37.45	56.08	29.86	60.0	− 11	3.54
138	Kans. 4	1.07	8.33	4.64	65.62	4.74	12.63	3.57	3.16	6,854	46.80	37.00	54.79	28.02	97.9	−107	4.05
139	Ill. 16	1.56	1.19	4.43	70.14	8.07	10.00	4.61	3.16	6,921	54.05	31.35	63.29	22.94	54.9	− 41	3.42
140	Va. 5A	.69	.66	3.52	72.23	3.37	18.80	.73	3.16	6,929	69.92	10.55	86.89	3.20	104.4	− 33	3.10
141	N. Mex. 5	1.19	.70	4.64	70.95	6.40	14.78	1.34	3.17	7,065	51.58	32.50	61.49	27.30	72.5	+ 95	3.84
142	Ind. 7	1.25	3.88	4.79	67.99	7.04	9.55	5.50	3.17	6,920	44.99	39.96	52.86	33.83	68.0	− 50	3.91
143	Kans. 1	1.09	4.34	4.49	68.22	4.98	13.14	3.74	3.18	6,891	50.01	33.11	60.17	26.69	90.2	− 84	3.87
144	Wyo. 5	1.52	.86	4.70	70.50	12.99	3.63	6.00	3.20	6,955	51.68	38.69	57.19	26.49	36.2	− 30	3.08
145	Ill. 11	1.59	2.07	4.49	69.91	7.88	11.15	3.11	3.21	6,978	52.71	33.03	61.48	24.60	57.0	− 12	3.50
146	Ind. T. 1	1.29	1.99	4.71	69.85	7.94	10.35	3.87	3.21	7,011	50.05	35.73	58.35	28.34	59.3	+ 21	3.72
146a	Colo. 3946	1.63	.71	4.85	70.39	12.70	5.48	4.24	3.21	7,075	53.04	37.24	58.75	24.65	38.2	+ 85	3.26
146b	Colo. 3586	1.63	1.31	4.79	70.00	11.04	6.39	4.84	3.22	7,024	50.49	38.28	56.88	27.87	43.4	+ 25	3.41
146c	Wyo. 4302	1.55	.64	4.14	71.09	11.63	6.33	4.62	3.22	6,911	54.85	34.20	61.60	22.84	35.6	− 88	2.69
147	Ill. 19B	1.48	.96	4.36	70.70	7.16	9.92	5.42	3.23	6,877	53.03	31.63	62.64	24.99	60.9	−123	3.47
147a	Colo. 3943	1.60	1.14	4.88	70.20	11.80	6.07	4.31	3.23	7,072	51.93	37.69	57.95	26.03	41.1	+ 72	3.40
147b	Cal. 3773	1.19	4.26	5.04	67.50	10.18	6.37	4.86	3.24	7,086	41.03	47.74	46.22	39.21	55.1	+ 75	4.37
148	Ohio 7	1.23	3.21	4.68	69.19	6.70	10.83	4.16	3.26	6,947	50.17	34.84	59.00	27.49	69.8	− 73	3.84
149	Ind. 7B	1.24	4.14	4.80	68.94	7.89	10.23	2.76	3.34	7,020	46.55	40.46	53.50	32.48	60.8	− 45	3.81
149a	Colo. 3546	1.60	.74	4.77	71.03	10.28	6.09	5.49	3.34	7,009	54.10	34.32	61.19	23.86	46.4	+ 4	3.48
150	Tenn. 6	1.01	.80	4.55	72.14	5.62	14.86	1.02	3.37	7,159	55.09	28.43	66.20	22.80	81.4	+ 79	3.85
151	Tenn. 9A	1.32	.96	4.49	71.84	5.57	14.46	1.36	3.38	7,135	56.22	27.96	66.78	21.71	80.6	+ 47	3.80
152	R. I. 1	.17	.07	.64	76.63	2.62	19.45	.42	3.41	6,229	75.11	5.02	93.73	1.98	24.4	−860	.31
153	Ind. 10	1.26	4.17	5.08	69.07	8.24	9.33	2.85	3.43	7,113	45.07	42.75	51.32	34.75	61.6	− 3	4.06
154	Ohio 8	1.35	2.97	4.86	70.18	8.68	8.76	3.19	3.46	7,055	48.26	39.79	54.81	31.31	56.6	− 82	3.78
154a	Wyo. 3480	1.79	.95	4.95	71.24	11.89	3.71	5.45	3.48	6,951	52.89	37.95	58.22	26.76	41.6	−188	3.46
155	Pa. 13	1.23	2.19	4.88	71.25	5.83	13.35	1.27	3.50	7,221	51.89	33.49	60.77	27.17	83.7	+ 50	4.15
156	Tenn. 1	1.65	1.63	4.74	71.36	7.26	11.49	1.87	3.48	7,199	52.71	33.93	60.84	26.14	65.3	+ 71	3.83
157	Tenn. 8B	1.25	4.84	4.42	69.59	4.35	14.41	1.14	3.52	7,096	50.87	33.58	60.23	26.90	101.6	− 65	3.88
158	Tenn. 7A	1.29	3.32	4.77	70.46	5.73	13.07	1.36	3.52	7,122	50.06	35.51	58.50	28.95	83.2	− 37	4.05
159	Ala. 1	1.66	.73	4.79	72.16	6.46	12.64	1.56	3.52	7,199	53.71	32.10	62.59	25.56	74.1	+ 42	3.98
160	Ind. T. 2	1.72	1.56	4.81	71.49	7.40	11.32	1.70	3.53	7,201	49.79	37.19	57.24	31.05	65.0	+ 40	3.88
160a	Colo. 3936	1.40	.44	4.76	72.65	10.99	6.95	2.81	3.55	7,243	53.25	36.99	59.01	26.70	43.3	+ 65	3.39
161	Ga. 1	1.13	1.31	4.02	72.92	5.03	14.97	.02	3.55	7,341	68.01	16.40	80.57	6.73	79.9	+163	3.39
161a	Wyo. 4323	1.48	.28	4.66	72.97	14.57	1.68	4.36	3.62	7,358	56.36	37.00	59.98	22.76	32.0	+145	2.84

162	Va. 5B	.74	.70	3.80	74.33	2.51	17.47	.45	3.65	7,112	71.00	11.08	86.50	4.48	151.4	−115	3.49
163	Pa. 3	.80	.77	2.58	75.21	2.23	16.33	2.08	3.68	6,929	74.32	7.27	91.09	1.18	115.7	−312	2.30
164	Tenn. 8A	1.17	4.45	4.85	70.45	4.57	13.64	1.05	3.68	7,179	51.26	34.05	60.05	27.24	106.1	− 63	4.28
165	Ill. 34A	1.53	2.51	4.72	71.55	8.66	8.90	2.13	3.68	7,324	53.36	35.61	59.97	25.42	54.5	+ 82	3.64
166	Ala. 4	1.25	1.14	4.78	73.09	5.09	13.67	.98	3.72	7,287	55.13	30.22	64.59	24.56	93.9	+ 26	4.14
166a	Colo. 3587	1.65	1.08	5.18	72.46	9.41	6.05	4.17	3.77	[b] 7,207	52.20	37.58	58.14	27.96	55.0	− 78	4.00
167	Ohio 12B	1.25	3.70	4.88	71.13	7.25	10.10	1.69	3.77	7,280	50.10	38.11	56.86	29.57	67.3	− 4	3.97
168	Ohio 10	1.32	3.00	5.30	71.28	9.15	7.71	2.24	3.78	7,368	48.55	41.50	53.91	31.89	59.9	+ 78	4.16
169	Pa. 6	1.27	1.98	4.53	72.87	5.30	12.78	1.27	3.78	7,301	53.52	32.43	62.26	26.55	85.4	+ 12	3.87
170	Ill. 11C	1.43	1.76	4.73	72.80	8.74	8.18	2.36	3.82	7,263	54.84	34.62	61.30	24.67	54.1	− 25	3.64
171	Ohio 9 A	1.22	3.25	4.40	72.07	8.04	8.56	2.47	3.83	7,331	50.89	38.08	57.20	29.39	54.8	+ 20	3.40
171a	Colo. 3938	1.76	.54	4.75	73.45	11.79	4.98	2.73	3.83	7,429	53.60	38.69	58.08	27.03	40.3	+118	3.28
171b	Colo. 3585	1.63	1.37	4.99	72.62	9.28	5.33	4.78	3.85	7,182	52.69	37.20	58.62	27.45	53.8	−138	3.84
171c	Colo. 3932	1.45	.42	4.86	73.96	10.69	5.41	3.19	3.91	7,364	55.49	35.91	60.71	24.99	45.5	+ 18	3.52
172	Ohio 12A	1.23	4.07	4.85	71.44	7.20	9.63	1.58	3.92	7,343	48.44	40.35	54.55	32.20	67.4	− 5	3.95
173	Kans. 5	1.09	3.86	4.76	71.90	5.76	10.79	1.84	3.95	7,333	54.97	32.40	62.92	28.54	82.6	− 29	4.04
173a	Wyo. 3570	1.18	.48	4.56	74.41	10.80	4.47	4.00	3.95	7,336	55.47	36.06	60.61	25.45	32.2	− 6	3.31
173b	Colo. 3939	1.73	.52	4.85	73.87	11.04	5.09	2.90	3.95	7,441	53.35	38.66	57.98	27.78	43.9	+ 78	3.47
174	Tenn. 4	1.63	1.03	4.93	73.62	7.01	10.00	1.77	3.96	7,333	54.32	33.91	62.69	26.09	70.3	− 34	4.05
174a	Colo. 4036	1.78	.53	5.03	73.65	12.89	1.94	4.18	3.97	7,465	54.63	31.25	58.19	25.82	39.6	+ 90	3.42
175	W. Va. 22B	1.18	1.04	4.87	74.16	6.92	10.09	1.74	3.99	7,344	53.80	34.37	61.02	27.45	70.4	− 37	4.01
175a	Colo. 4225	1.50	1.03	5.30	73.73	9.06	5.87	3.51	4.08	[b] 7,316	51.12	39.50	56.41	30.67	58.5	−105	4.17
176	Pa. 17	1.44	1.56	4.71	74.06	4.83	12.31	1.09	4.08	7,448	57.89	28.71	66.84	21.83	97.5	+ 28	4.11
176a	Colo. 7573	1.40	.66	4.95	74.41	9.43	5.82	3.33	4.08	7,461	53.77	37.08	59.19	27.74	52.5	+ 21	3.77
177	W. Va. 25	1.43	.66	4.80	74.61	9.16	7.39	1.95	4.08	7,608	54.42	36.24	60.03	27.06	52.4	+188	3.65
178	Ohio 4	1.33	3.52	4.82	72.68	6.24	9.25	2.16	4.17	7,365	50.61	37.98	57.13	30.37	77.2	− 95	4.04
179	Ark 8	.58	2.14	3.35	75.77	2.73	14.65	.83	4.18	7,241	73.55	10.97	87.01	2.93	122.7	−215	3.01
179a	Colo. 4048	1.86	.96	5.02	74.10	11.96	3.00	3.10	4.18	7,564	55.32	38.58	58.91	25.34	42.0	+104	3.53
180	Ky. 8	1.23	1.22	4.61	74.99	7.44	8.18	2.33	4.24	7,598	57.48	32.01	64.23	23.35	61.9	+115	3.68
181	Ark. 12	1.38	1.68	3.64	75.49	3.07	13.52	1.22	4.27	7,282	68.58	16.68	80.45	9.15	118.5	−215	3.26
182	Ark. 1	1.47	1.27	3.87	75.68	3.66	12.88	1.17	4.30	7,450	68.12	17.83	79.25	10.00	105.8	− 60	3.41
183	Ohio 5	1.45	1.76	4.84	74.44	8.04	7.48	1.99	4.31	7,501	54.13	36.40	59.79	27.27	60.2	− 13	3.84
184	Utah 1	1.43	.57	5.29	75.18	10.13	5.06	2.34	4.35	7,595	48.92	43.68	52.68	34.93	52.2	+ 60	4.02
185	Tenn. 5	1.69	3.38	4.82	73.23	5.30	10.20	1.35	4.37	7,456	53.32	35.13	60.28	27.19	90.4	− 80	4.16
186	Tenn. 3	1.78	1.02	5.06	74.80	7.81	7.26	2.25	4.38	7,489	54.79	35.68	60.56	26.75	64.1	− 50	4.08
187	Ohio 6	1.17	3.47	5.00	73.58	6.45	8.87	1.47	4.42	7,425	51.45	38.21	57.38	30.08	77.5	−130	4.19
188	Ind. T. 2C	1.88	1.85	4.87	74.50	6.60	8.87	1.43	4.45	7,505	53.08	36.62	59.18	28.75	73.8	− 55	4.04
189	Pa. 22	1.58	1.03	4.67	75.19	5.63	10.49	.91	4.47	7,632	59.57	29.03	67.23	21.30	82.9	+ 62	3.97
190	Md. 1	1.32	1.51	3.78	76.28	2.85	13.32	.94	4.48	7,469	69.40	16.34	80.94	9.02	132.6	−106	3.42
191	Pa. 12	1.46	2.21	4.62	74.89	6.23	9.32	1.27	4.49	7,621	58.64	30.77	65.58	21.69	74.2	+ 44	3.84
192	W. Va. 22A	1.22	.85	4.89	76.01	7.60	7.98	1.45	4.50	7,645	56.40	34.17	62.27	25.79	64.3	+ 65	3.94
193	Pa. 7	1.55	2.15	4.41	75.19	2.90	12.88	.92	4.52	7,549	64.90	21.30	75.30	13.69	152.0	− 37	4.05
194	Tenn. 9C	1.28	.67	4.67	76.37	6.00	9.58	1.43	4.54	7,563	59.26	29.73	66.59	22.40	77.8	− 32	3.92
195	Ark. 3	1.55	1.30	3.98	76.37	4.20	11.80	.80	4.57	7,586	67.65	19.75	77.40	11.41	94.8	− 15	3.46
196	Pa. 21	1.57	.90	4.52	76.34	6.61	9.09	.97	4.61	7,751	60.85	29.09	67.66	20.30	68.4	+154	3.68
197	Pa. 4	1.46	1.29	4.71	76.00	4.92	10.64	.97	4.62	7,616	57.44	30.95	64.98	24.42	95.7	− 4	4.11
198	W. Va. 3	1.44	1.07	4.80	76.12	5.20	10.37	1.00	4.62	7,631	58.38	30.25	65.89	23.31	92.3	+ 11	4.15
199	W. Va. 23B	1.19	1.36	4.88	76.02	6.94	8.15	1.46	4.64	7,661	55.47	34.92	61.23	27.03	70.3	+ 36	4.01
200	W. Va. 5	1.48	1.99	4.71	76.32	5.63	10.18	.65	4.65	7,682	59.97	29.20	67.25	21.46	83.6	+ 55	4.01

* Moisture (H_2O) is included as a separate percentage to conserve the "air-dried" basis of the analyses and calorific determinations.
[a] Coals more or less weathered.
[b] From shallow mine or country bank.

TABLE 2.—*The coals of Table 1, showing moisture-free hydrogen and oxygen; fixed carbon in pure coal; hydrogen to oxygen, and volatile carbon to carbon ratios; "available" hydrogen; and variance from C : (O+ash) ratio and efficiency curve*—Continued.

No.	Designation of coal.	N.	S.	H (−H_2O).	C.	O (−H_2O).	Ash.	H_2O.*	$\frac{C}{O+ash}$	Calories.	Proximate. Fixed carbon.	Proximate. Volatile matter.	Fixed carbon in pure coal.	$\frac{Vol.\ C}{C}$	$\frac{H}{O}$	Variance from curve (calories).	Available H.
														Per cent.	*Per ct.*		
201	W. Va. 16	1.53	1.26	4.66	76.09	6.48	8.76	1.22	4.66	7,609	56.96	33.06	63.27	25.14	71.9	− 15	3.85
202	Pa. 19	1.42	1.08	4.81	76.25	6.86	8.57	1.01	4.67	7,752	57.81	32.57	63.98	24.13	70.1	+115	3.95
203	Mo. 4	.75	5.55	5.17	72.45	5.46	5.23	5.39	4.68	7,516	44.47	44.91	49.76	38.62	94.6	−120	4.49
204	Ky. 1B	1.73	1.16	4.89	75.89	6.22	8.54	1.57	4.69	7,623	55.14	34.75	61.43	27.34	78.6	− 17	4.11
205	W. Va. 2	1.37	3.50	4.93	74.44	6.40	7.90	1.46	4.70	7,700	50.50	40.14	55.71	32.16	77.0	+157	4.13
206	Ark. 7A	1.32	2.12	3.42	76.37	3.38	12.29	.60	4.71	7,413	70.00	17.11	80.36	7.64	101.0	−230	3.50
207	Tenn. 2	1.81	1.01	4.98	75.97	7.25	7.03	1.95	4.76	7,630	54.05	36.97	59.38	29.53	68.7	− 25	4.07
208	W. Va. 4B	1.60	1.10	4.37	76.72	4.48	10.38	1.35	4.77	7,626	60.88	27.39	68.93	20.65	97.5	− 38	3.81
208a	Wyo. 4303	1.31	.94	4.81	76.84	10.81	3.23	2.06	4.84	7,812	57.53	37.18	60.74	25.13	44.5	+126	3.46
208b	Colo. 4010	1.56	.45	5.03	77.05	8.38	6.32	1.21	4.88	7,860	57.30	35.17	61.97	25.63	60.0	+163	3.98
208c	Ala. 3499	1.69	1.10	4.76	76.64	6.14	8.48	1.19	4.88	7,613	59.43	30.90	65.79	22.46	77.5	− 83	3.99
209	W. Va. 23A	1.45	1.24	4.95	76.57	6.50	7.71	1.58	4.90	7,643	55.50	35.20	61.18	27.51	76.2	− 57	4.14
210	Va. 6	1.33	1.27	4.37	77.21	4.87	10.30	.65	4.90	7,757	64.77	24.28	72.39	16.11	89.7	+ 57	3.76
210a	Ala. 3745	1.13	.88	4.82	77.40	7.80	6.30	1.67	4.96	7,764	59.11	32.92	64.23	23.63	61.8	+ 48	3.84
211	Ark. 5	1.39	2.01	3.60	77.29	2.22	12.21	1.28	4.96	7,443	73.69	12.83	85.18	4.65	162.1	−270	3.35
211a	Colo. 3552	1.50	1.38	5.06	76.63	8.05	5.31	2.07	5.04	[a] 7,676	54.22	38.40	58.54	29.24	62.9	− 62	4.05
212	Pa. 9	1.29	2.09	3.94	77.42	3.14	11.63	.50	5.09	7,657	70.12	17.75	79.91	9.42	125.5	− 92	3.55
213	W. Va. 11	1.04	.53	3.94	79.12	3.07	11.50	.80	5.17	7,761	70.80	16.90	80.73	10.55	128.4	− 6	3.56
214	Pa. 11	1.45	1.19	4.94	77.32	6.41	7.33	1.36	5.17	7,699	57.03	34.28	62.46	26.24	77.1	− 70	4.14
215	W. Va. 15	1.44	2.56	4.91	76.52	4.82	8.63	1.12	5.29	7,743	52.60	37.65	58.28	31.26	101.9	− 54	4.31
215a	Wyo. 4299	.85	.71	5.32	78.19	9.05	3.48	2.40	5.33	7,713	57.33	36.79	60.91	26.68	58.8	− 92	4.20
216	W. Va. 4	1.50	.90	4.74	78.21	5.24	8.43	.98	5.37	7,855	61.87	28.72	68.29	20.89	90.5	+ 43	4.09
216a	Ala. 3771	1.53	.44	4.94	78.67	6.81	5.75	1.86	5.53	7,791	58.75	33.64	63.59	25.32	72.5	− 42	4.09
217	Va. 4	1.35	.81	4.86	78.56	7.60	4.42	2.40	5.55	7,902	55.54	37.64	59.60	29.30	63.9	+ 55	3.91
218	Va. 2B	1.45	.94	4.92	78.51	7.01	5.69	1.48	5.59	7,890	57.02	35.81	61.42	27.37	70.2	+ 31	4.04
219	W. Va. 1	1.55	.90	5.11	78.31	6.41	6.37	1.94	5.60	7,869	55.36	36.92	60.00	29.31	79.7	+ 9	4.31
220	Pa. 10	1.59	1.28	4.99	78.16	6.40	6.25	1.33	5.64	7.877	57.04	35.38	61.71	27.02	78.0	+ 9	4.19
221	Va. 1	1.27	1.23	4.98	78.47	7.50	4.85	1.70	5.66	7.870	57.66	35.49	61.70	26.52	66.4	− 1	4.04
222	W. Va. 20	1.37	1.41	4.96	78.39	4.93	8.20	.74	5.68	7,812	58.17	32.89	63.88	25.79	100.6	− 64	4.34
223	W. Va. 8	1.38	.92	4.98	78.75	5.01	7.36	1.60	5.71	7,863	58.92	32.12	64.72	25.18	99.4	− 17	4.35
224	Ky. 6	1.48	.58	5.02	78.94	8.17	2.82	2.99	5.78	7,807	56.88	37.31	60.39	27.95	61.4	− 95	4.00
225	W. Va. 17	1.41	1.49	4.40	78.95	4.42	8.33	1.00	5.78	7,903	62.68	27.99	69.13	20.61	99.6	+ 5	3.85
226	Pa. 5	1.55	.89	5.04	78.78	6.16	6.11	1.47	5.80	7,864	57.59	34.83	62.31	26.90	81.8	− 36	4.27
227	Pa. 16	1.33	1.65	4.42	79.00	5.05	8.19	.36	5.83	7,812	68.78	22.67	75.21	12.94	87.5	− 90	3.79
227a	Ala. 3769	1.25	1.10	4.83	79.16	7.39	4.65	1.62	5.87	7,964	59.87	33.86	63.87	24.37	65.4	+ 52	3.91
228	Pa. 20	1.16	2.96	4.50	78.23	1.80	10.93	.42	5.90	7,692	72.17	16.48	81.41	7.74	250.0	−224	4.28
229	Ky. 1	1.85	1.24	5.15	78.31	7.09	4.44	1.92	5.91	7,955	57.08	36.56	60.96	27.11	72.6	+ 35	4.26

230	Pa. 15B	1.18	4.06	4.24	77.52	1.97	10.55	.48	5.98	7,781	70.49	18.48	79.23	9.07	215.2	−150	4.02
231	W. Va. 18	1.45	.68	4.77	79.65	6.25	5.92	1.28	5.98	7,963	59.03	33.77	63.61	25.88	76.3	+ 33	3.99
231a	Ala. 3744	1.33	.67	5.09	79.50	8.68	3.21	1.52	6.01	8,115	60.68	34.59	63.69	33.67	58.6	+177	4.00
231b	Colo. 4047	1.83	.52	4.57	79.77	3.91	8.64	.76	6.03	7,977	69.07	21.53	76.24	13.41	116.9	+ 37	4.08
232	W. Va. 9	1.63	.80	4.93	79.35	5.50	6.79	1.01	6.03	7,984	62.67	29.53	68.00	21.02	89.6	+ 44	4.24
233	Ky. 5	1.61	.69	4.81	79.67	7.81	3.81	1.60	6.10	7,958	58.56	36.03	61.91	26.49	61.5	+ 8	3.83
234	W. Va. 21	1.52	1.35	5.04	79.15	6.50	4.95	1.50	6.19	7,915	56.39	37.16	60.28	28.75	77.5	− 42	4.23
235	Ala. 6	1.45	.63	4.75	80.25	5.18	6.88	.85	6.26	8,011	65.47	26.80	70.95	18.41	91.6	+ 36	4.10
236	Ark. 2	1.40	1.90	4.05	80.03	2.54	9.34	.74	6.38	7,756	73.66	16.26	81.92	7.96	159.5	−230	3.73
237	Pa. 15	1.17	3.88	4.39	78.61	1.52	10.09	.34	6.60	7,885	71.45	18.12	79.77	9.11	288.8	−133	4.20
238	Pa. 18	1.23	1.55	4.49	80.74	2.68	8.63	.38	6.81	7,926	74.69	16.10	82.27	7.49	167.5	−115	4.16
239	W. Va. 14	1.56	1.06	4.92	80.73	6.30	3.38	2.05	7.01	8,090	64.57	30.00	68.28	20.02	78.1	+ 25	4.13
239a	Ark. 3174	1.49	2.85	3.80	80.48	1.52	9.27	.59	7.11	7,824	75.12	15.02	83.34	6.65	250.0	−252	3.61
239b	Pa. "L"	1.27	2.29	3.97	81.10	2.42	8.31	.64	7.18	7,934	76.38	14.67	83.89	5.82	164.0	−147	3.67
240	W. Va. 7	1.05	1.20	4.30	82.41	5.19	5.09	.76	7.52	8,254	73.61	20.54	78.18	10.68	82.8	+136	3.65
241	Md. 2	1.49	.86	4.46	82.39	2.77	7.29	.74	7.68	8,086	73.83	18.14	81.36	10.39	161.1	− 49	4.11
242	Ind. T. 9	1.68	1.24	4.28	82.06	1.69	8.41	.64	7.69	7,948	76.66	14.29	84.29	6.58	253.2	−185	4.07
242a	Ala. 3770	1.55	.49	5.20	82.09	5.55	3.84	1.28	7.78	8,180	60.32	34.56	63.58	26.52	93.7	+ 38	4.51
243	Va. 3	1.63	.68	4.94	82.16	5.14	4.58	.87	7.83	8,220	62.19	32.36	65.77	24.31	96.1	+ 73	4.30
244	Pa. 8	1.29	.97	4.30	83.11	2.87	6.83	.63	8.10	8,170	75.22	17.32	81.28	9.49	149.8	− 4	3.94
245	W. Va. 13	1.36	.91	5.02	82.65	4.87	4.01	1.17	8.32	8,234	62.39	31.87	66.39	23.83	103.1	+ 39	4.41
246	W. Va. 12A	1.34	.69	4.29	83.63	2.48	6.95	.62	8.38	8,185	74.38	18.05	80.47	11.06	173.0	− 15	3.98
247	W. Va. 12	1.33	.85	4.85	83.18	1.64	6.22	1.93	8.68	8,300	74.38	18.05	80.47	10.58	295.7	+ 55	4.64
248	W. Va. 6	1.70	.66	4.63	83.62	3.66	5.09	.64	8.97	8,301	72.53	21.74	76.94	13.26	126.5	+ 43	4.17
249	W. Va. 19	1.61	.91	4.58	83.56	3.53	5.13	.68	9.01	8,203	70.91	23.28	75.28	15.14	129.7	− 56	4.14
250	W. Va. 10	1.07	.57	4.51	85.91	2.66	4.63	.65	11.78	8,439	75.92	18.80	80.15	11.63	169.6	+ 30	4.18

* Moisture (H_2O) is included as a separate percentage to conserve the "air-dried" basis of the analyses and calorific determinations.
[a] Coals more or less weathered.

The slight recalculation of the analyses shown in this table offers the data necessary for the observation of the relative amounts of hydrogen and oxygen assumed to be in actual hydrocarbon compounds; and these, as well as the relative amounts of volatile carbon (total carbon less fixed carbon) are made available for comparison as ratios, H:O and VC:C, without further departure from the air-dried basis of the analysis. The fixed carbon of the proximate analysis not only shows marked local variations, but also is subject to considerable error in the process of determination. By combining the volatile carbon in ratio with the more constant and accurately determined total carbon, following the method employed by Professor Parr,[a] the fixed carbon error of the proximate analysis is minimized.

The criteria for the study of the composition of the fuels are advantageously supplemented by the calculation of the fixed carbon in "pure coal" (ash and water free) by the method recommended by Professor Grout.[b] By this method the fixed carbon in "pure coal" is determined by dividing the fixed carbon by the sum of the fixed carbon and "volatile combustible matter" as given in the proximate analysis. For use in comparison the variance of the ascertained calorific value from the curve value is noted for each coal; also the amount of available hydrogen.

COMPENSATED CALORIFIC VALUES.

It may be of interest to remark at this point that the C:(O + ash) ratios, if recalculated on the moisture-free basis of the oxygen as given in Table 2, fluctuate widely from the ratios in Table 1; but if the calories also be recalculated to compensate for the eliminated water weight—that is, if the ascertained calories on an air-dried basis be divided by 100 minus moisture in air-dried coal—we shall have corresponding new theoretical efficiencies in larger denomination. On referring the new ratio to its serial position higher in the scale of the old ratios it will generally be found that the compensated calorific value will again fall near its proper, though entirely new and different, position in the succession of calorific values. For example, the C:(O + ash) ratio of No. 25, when computed from the moisture-free oxygen of Table 2, will be found to be 3.23 instead of 1.73; and the air-dried efficiency of 5,753 calories is changed to 6,989 calories when compensated for a loss of 17.69 per cent weight of moisture. Inspection of the ratio series in Table 2, or of the curve, shows that a coal having a ratio of 3.23 should have an efficiency of approximately 7,000 calories.

A few other examples, taken at random, of coals having high moisture may be presented. No. 64 of the tables, a New Mexico Cretaceous coal, whose ratio is 2.28, its efficiency error being very small, has a moisture of 10.86 per cent. On the moisture-free basis the

[a] Bull. Geol. Survey Illinois No. 3, 1906, p. 31.

[b] Econ. Geology, vol. 2, 1907, p. 240.

ratio of this coal becomes 3.46 and the compensated efficiency 7,127; by reference to the curve or to the proper point in the succession of the ratios in Table 2 it will be seen that the calorific value of a coal having a ratio of 3.46 should be about 7,137. In other words, this coal, whose curve error was +6 on the air-dried basis, appears to have an error of +10 when projected on the moisture-free basis among the high-grade bituminous coals of Tennessee, Ohio, and Pennsylvania. Another coal having relatively high moisture content in its air-dried condition is No. 144 of the tables. This coal from Wyoming has a moisture content of 6 per cent and a ratio of 3.20, its efficiency error being −30; on the moisture-free basis the ratio of this coal becomes 4.23, the compensated calories becoming 7,399. Passing up the scale of the ratios it appears that a coal having a ratio of 4.23 should have a calorific value of a little less than 7,480; so that this coal which had a deficiency of 30 on the air-dried basis, when projected as moisture-free with a higher ratio, shows a deficiency of about 80 calories in its new position on the curve. No. 203, a Paleozoic coal from Missouri, with moisture 5.39 and a ratio of 4.68, has an error of −120 calories, probably due to the very high sulphur. The moisture-free ratio of this coal is 6.78, the compensated calories being 7,944. The calorific value for a coal having a ratio of 6.78 should, according to the curve, be not far from 8,030; so that the error when this coal is projected on the moisture-free basis to a position among the highest grade semi-bituminous coals becomes −85 calories instead of −120, as developed on the air-dried basis. Again, No. 32, a Laramie coal from Lafayette, Colo., has a moisture of 13.39 and a ratio of 1.95, its variance from the curve being −45 calories; the ratio on the moisture-free basis for this coal is 3.17, the recalculated efficiency being 6,929. Passing down the columns to No. 142 we find that the efficiency for a coal with a ratio of 3.17 should be 6,970, showing an error of −41; in other words, this coal, which had an error of −45 in its normal air-dried condition, has almost the identical error when recalculated to eliminate the moisture and referred to a new position very much higher in the curve.

VALUE OF MOISTURE-FREE DATA.

Comparisons of this kind are of value chiefly as indicating the consistent progression of the ratios and the stability of the curve as applied both to moisture-laden and to moisture-free coals. The dry coals fall in the same scale as the air-dried and with nearly equal precision. For the entire series of coals in the table the average total for the carbon, oxygen, and ash is about 91.82. It is perhaps permissible to interpret this agreement of the moisture-free ratios and compensated values as indicating approximate equivalence in anti-calorific value for the oxygen of the moisture and the oxygen of the coal itself, as well as for the ash.

An inspection of Table 2 shows that in many coals of the same ratio and of nearly equal efficiency there are striking differences in the amounts of fixed carbon (in pure coal), and a wide range in the H:O ratios, the latter being also apparent with respect to coals with the same percentage of fixed carbon. Similarly a less noticeable fluctuation is seen in the relations of the VC:C ratios both in coals of the same efficiency and in those of equal fixed carbon. The variations thus disclosed appear, in some instances, to explain the departures of the ascertained efficiencies from the calorific values indicated by the ratio curve.

The data in this table offer not only a better opportunity to study the relative values of oxygen and ash, since the oxygen is restricted to that assumed to belong to the coal itself, but also a basis for considering the comparative anticalorific importance of the oxygen of the moisture in the air-dried samples tested. The latter question becomes, under the circumstances, largely a matter of observation of the effects of the varying percentages of oxygen, ash, and moisture, in a miscellaneous and somewhat heterogeneous aggregate of coals.

The relative values of these impurities may be more precisely estimated if the coals are grouped as to kinds and districts, rather than merely by the ratio sequence, and each kind is studied by itself. Possibly, also, new and slightly modified curves will be found in groups of this sort.

RELATIVE NEGATIVE VALUE OF ASH AND OXYGEN.

The question whether oxygen or ash is negatively more potent is difficult to determine from the comparison of so wide a range in kind, condition, and age of coals. The difficulty is further complicated and rendered more delicate by the fact that so many of the errors or variances from the curve lie within the range of error in the work of the calorimeter, the average ratio-curve error for the total number of analyses being very much less than 1 per cent of the average calorific value. The question is therefore, for the present, left somewhat in doubt. From study of the tables, however, I am inclined to believe that the oxygen is possibly of slightly greater anticalorific importance in the lowest grade of bituminous and the subordinate group of coals, while in the higher bituminous and the semibituminous fuels the ash is probably of greater negative value. From a casual glance it would appear that in the air-dried samples the greater anticalorific value lay in the oxygen. But the possibility that many of these coals have taken up oxygen under exposure to air or weathering conditions enjoins caution in forming conclusions; for, as I shall indicate later, the oxidized coals are generally characterized by deficiencies, as compared to the curve, in calorific value. On the other

hand, the arrangement of the coals is such that the slightly greater available hydrogen prevalent in the coals with high ash (on account of their generally higher class) may be regarded as counterbalancing a small margin of the disadvantage attributable to the ash, thus appearing to indicate for the ash a slightly greater anticalorific value. However, the number of instances of parity of coals with alternating percentages of the two impurities, in which no unusual available hydrogen accompanies the high ash, is so great as to preclude any important difference of negative value in favor of the ash. But it will be observed in passing down the columns of the table that coals with high hydrogen are usually accompanied also by high sulphur, whose diluent influence in the analysis tends to neutralize the effect of the high available hydrogen. Thus it becomes more readily practicable in general to treat the hydrogen as constant, and so to ignore it, along with the nitrogen and sulphur, in forecasting the calorific values of the fuels by means only of the C : (O + ash) ratios.

On the whole, the calorimetric tests make it evident that high oxygen (with its usually slightly lower available hydrogen concomitant) and high ash (in most cases accompanied by slightly higher available hydrogen) counterbalance, so that practically, taking coals as they come, the calorific values of two coals in which the two great impurities alternate, carbon being constant, are almost exactly equal. The facts presented in the tables show plainly and conclusively why the Paleozoic coals of the Eastern Interior basin can not possess the efficiency of Appalachian standard coals of the same ash percentage; and why the very low-ash, but high-oxygen samples of low-class, subbituminous, and lignitic coals of the Cretaceous or Tertiary exhibit a calorific efficiency no greater than that of high-class Paleozoic coals having contrastingly high ash and correspondingly low oxygen, if the total carbon is the same.

It will later be shown that some of the maximum variations in the available hydrogen are responsible for a number of the larger variances from the ratio curve in Tables 1 and 2. The latter are not, however, sufficiently numerous or large to require a coefficient for compensation.

It is probable that for a group of cannels and bogheads in which the hydrogen is excessively high a higher special cannel curve will be found desirable. The construction of such a curve based on the ascertained component ratios and efficiencies will be much simpler, and perhaps in general more reliable, than a coefficient for the abnormally high hydrogen of this group.

RELATIVE EFFECT OF THE OXYGEN OF MOISTURE.

The obstacles to distinguishing between the negative values of the oxygen of the coal proper and the oxygen of moisture, in the calo-

rimeter results, are largely the same as those affecting the discrimination between the relative values of ash and oxygen. In fact, the effect of moisture on the standing of the coals as determined by the C : (O + ash) ratios is generally so little as to excite surprise. For example, the efficiency shown in the test of No. 31, a Fort Union coal from Deer Lodge, Mont., which has 9.05 per cent moisture, or No. 32, the Laramie coal at Lafayette, Colo., with 13.49 per cent of moisture, differs less than 1 per cent from the efficiency of No. 30, the Pocahontas bone at Gary, W. Va., which has but 0.52 per cent moisture. Other coals, such as Nos. 71, 72, and 72a, afford similar striking contrasts, the calorific values being so little affected and so regularly conformable to the curve as to make it clear that no great difference can exist between the negative values of the oxygen of moisture and that combined in the coal.

In connection with this question of the relative values of the two oxygens attention should be called to the approximate coincidence and complete conformity of the ratios of the moisture-free coals and of their respective compensated calorific values with the curve of the air-dried coals, as noted on page 34.

A review of the efficiency variations in Table 2 tends to show slightly more frequent calorific deficiencies in coals having abnormally high moisture. But, on the other hand, allowance must be made for the fact that most of the samples very high in moisture are low in the scale of coal formation, and consequently most susceptible to deterioration on exposure to atmospheric oxygen. There is no doubt in my mind that many such deficiency variances are due to this cause. Furthermore, so many of the instances of calorific deficiency which might perhaps correctly be ascribed to high moisture are attendant on unusual deficiencies in the available hydrogen, that at the end one is left uncertain whether, so far as may be judged by the behavior of the air-dried samples in the calorimeter, the moisture oxygen in general differs much from other oxygen in its harmful effect. This does not, of course, preclude the recognition of a difference under practical boiler-grate conditions.

The varying capacity of coals of the same age and district, under apparently the same conditions as to progressive metamorphism, to hold water seems to depend largely both on the character of the original constituent organic matter and on the conditions governing the first or biochemical stage of coal formation.

Since coals with high oxygen and low ash have the same calorific values as others in which the terms are reversed, if the other percentages are constant, it becomes evident that, in general, the carbon-oxygen ratio of the coal (ash free, or ash constant) corresponds fairly closely to the rank of the coal in efficiency. The same ratio also indicates, for coal of the same origin, its progress in the scale of coal transformation.

ESTIMATE OF THE EMPIRICAL ANTICALORIFIC VALUE OF OXYGEN.

NEGATIVE VALUE OF OXYGEN AND ASH.

In the preceding pages it has been shown that, in general, throughout a miscellaneous collection of coals of all grades, the heating value of the fuel is roughly indicated by the amount of the total carbon as compared to the sum of the oxygen and ash. Also that, so far as concerns the calorific efficiencies of the coals, alternating amounts of oxygen and ash essentially offset each other, providing the total carbon be constant, though strictly speaking a slight excess of negative potency appears to lie in the ash. On the whole, however, in view of the tendency of two of the assumed constants, sulphur and hydrogen, to compensate each other, as will be pointed out in the next section, we may conclude that, from the practical standpoint, oxygen and ash may be regarded, according to the calorimetric tests, as essentially interchangeable.

APPLICATION OF THE CURVE.

The curve platted from the C : (O + ash) ratios and the calorific efficiencies provides an indirect method of ascertaining the average amounts of calorific change corresponding to any given ratio change, for different parts of the curve. For any one length or section of the curve the amount of this calorific change may be taken as a scale of approximately equal units, by which any fractional ratio change may be measured. Hence it is not difficult roughly to estimate the anticalorific values of 1 per cent added to or subtracted from the oxygen or ash in a coal analysis.

Inspection of the curve, as provisionally drawn, shows the following approximate values of curve segments covering changes of 0.05 and 0.01 in the ratios (horizontal component) at a number of points:

Calorific changes corresponding to ratio changes of 0.05 and 0.01 at stated points in curve.

Part of curve.	Ratio change 0.05.	Ratio change 0.01.
Ratio.	*Calories.*	*Calories.*
1.00	115.0	23.0
1.50	80.0	16.0
2.00	50.0	10.0
2.50	40.0	8.0
3.00	35.0	7.0
3.50	28.0	5.6
4.00	22.0	4.4
4.50	19.0	3.8
5.00	13.3	2.6
5.50	10.0	2.0
6.00	8.0	1.6

FLUCTUATION IN EFFECTS OF CHANGES.

The practical application of these units at once discloses wide fluctuations in the relative effects of changes of 1 per cent in the joint impurity. These are due (1) to the constantly changing elements upon which the ratios are based, and (2) to the marked difference between the ratios as a curve component, with constantly progressive dividends and divisors, and the component of the efficiencies. The essential result is an increase in the negative value of the impurities in passing from one part of the curve to another, as the following figures show:

At ratio 1.00 the value of 1 per cent of added oxygen or ash is about 47.5 calories; at ratio 1.50 the value of 1 per cent of added or subtracted oxygen or ash averages approximately 64.5 calories; at 2.00 the average approximates 65.4 calories; at 2.50 it approximates 78 calories; at 3.00 it approximates 92 calories, the effect becoming more strongly marked in subtraction; at 3.50 it averages about 97 calories; at 4.00 the variation between the added and the subtracted 1 per cent is slightly greater, the average of both at that point being about 93.9; the decline is still more marked at 5.00, where 1 per cent of the joint impurity is valued at nearly 82.2 calories, while at 5.50 its effect is about 77 calories; and at 6.00 it falls to about 72 calories. At this point (ratio 6.00) deduction of 1 per cent of the impurity amounts to an addition of about 77.6 calories, while addition of the same percentage causes a change of about 69 calories. These values are based in each case on the average of the differences between the ratios in Table 1 and those obtained by adding 1 per cent and by subtracting 1 per cent from the total oxygen plus ash.

ESTIMATE APPLIED TO THE ANALYSES.

A clearer idea of the application of this indirect method may easily be gained by practical experimentation with the analyses in the table, the ratio changes resulting from increase or diminution of the impurities being compared with the calorific differences indicated by the corresponding changes in the curve. For example, No. 145 of Table 1 has a ratio of 3.21, the corresponding efficiency being 6,990 calories. The addition of 3 per cent of oxygen or ash to this coal produces a coal whose C:(O + ash) ratio will be 2.82. The calorific value of a compensated coal having this ratio will be found to be about 6,750 calories, showing a difference of about 240 calories on account of the addition of 3 per cent of oxygen, the impairment averaging, therefore, about 80 calories to each 1 per cent of added impurity. If, on the contrary, we subtract 3 per cent from the oxygen or ash of the coal in No. 145, we shall have a coal with a ratio of 3.72, whose efficiency, according to the curve, will be about 7,260 calories,

an increase of approximately 270 calories, as the result of deducting 3 per cent of impurity; that is, 90 calories to each 1 per cent. Or, to take another example at random, No. 183 in Table 1, with a ratio of 4.31, has a calorific curve value of 7,515. The addition of 3 per cent of oxygen or ash produces a coal with a ratio of 3.67, whose efficiency will be approximately 7,238 calories, a calorific difference of 277, being approximately 92 calories to each added 1 per cent of the joint impurity. Contrariwise, the subtraction of 3 per cent in the analysis of No. 183 defines a coal having a ratio of 5.21, according to which the calorific value of the coal will be 7,780, showing a difference of approximately 265 calories resulting from the difference in the impurity, or 88 calories as the average advantage derived from the elimination of 1 per cent of the impurity.

Tests of this kind may be applied to all of the coals in the table. They are, however, inaccurate and of little value, though interesting. The fluctuations are very wide and vary from the amounts calculated from the value of the combustible displaced or concentrated by the addition or subtraction, respectively, of the inert impurity.

CAUSES OF VARIANCE FROM THE CURVE.

GENERAL STATEMENT.

The causes of the wider fluctuations of the ascertained efficiencies from the C:(O + ash) ratio and efficiency curve appear in most cases to lie in the percentages of those elements that have been ignored as negligible constants, hydrogen, sulphur, and nitrogen. Besides these we have, also, among the data of the analysis the less definite, though no less absolute, effects of (1) oxidation by weathering and (2) the devolatilization incidental to anthracitization. There are, however, other causes which seem incapable of detection from the mere ultimate analyses. Although of subordinate importance, these will first be considered.

CAUSES NOT SHOWN BY ULTIMATE ANALYSES.

First are the differences in the hydrocarbon compounds entering into the substance of the coal. These compounds, whose number and structure appear still to be largely unknown, presumably vary in stability, in quantity, and more or less in calorific values. Some of these differences are probably due to the nature of the original ingredients. The bogheads, for example, are described as largely composed of the remains of gelatinous algæ, which appear to have exercised a selective attraction for certain bituminous compounds, and which are excessively rich in volatile combustible having an illuminating value far above that derived from ordinary gas coals. Pyropissite, which is largely composed of resins, is an extreme example in this category.

The obviously abundant resin in some of our Cretaceous low-grade[a] bituminous and subbituminous coals and lignites doubtless contributes to the calorific excess which attends many of the unweathered samples. A number of these coals figure among the extreme excess variances among the efficiencies marked "L" to the left in the curve diagram, Plate I.

Another, possibly the principal, of the intangible causes not revealed by the analyses is the error in oxygen determination in the process of making the ultimate analysis. Since the oxygen is the residual of the analysis, ascertained by subtracting from a total of 100 per cent the sum of the percentages of the other elements, it is evident that it contains the residual error which may possibly be cumulative. Among the lower ratios a slight error in oxygen determination does not cause a very marked effect on the calorific variance, but in the higher grade coals a fraction of 1 per cent may make a considerable difference in the ratios, and a consequent erroneous indication of the efficiency. In a coal having a ratio of 2.00 an error of about 1 per cent of oxygen in the analyses will amount to a curve difference of about 63 calories. It is possible that the surprisingly low oxygen of several of the semibituminous coals[b] may in part be due to error in its determination.

An important source of error in oxygen determinations is connected with the presence of pyrite in the coals, for the production of sulphur dioxide causes an oxygen deficiency equal to three-eighths of the sulphur in the pyrite. The residual error (oxygen) of the analysis is also affected by the reduction of iron carbonate when that is present in the coal, the results being too high carbon and oxygen and too low ash. Small errors in oxygen calculations are also due to the recognized tendency in high-ash coals of the aluminous silts to hold back hydrogen and of siliceous sediments to withhold oxygen. The relatively few cases in which the marked variances are not fairly well explained by these or other causes, and in particular the very small average error of the efficiency curve, indicate a high standard of accuracy in the coal analyses on which this report is based.

As a third cause of variance not visible in the analyses is the oxygen taken up on exposure to the air or weathering, which constitutes a serious cause of variance on the side of deficiency. This matter will be again referred to (p. 63) in connection with the subject of the weathering of coals.

CAUSES RECOGNIZABLE IN ANALYSES.

The causes of variance that may, frequently at least, be recognized in the analyses will now be considered.

---

[a] By low grade is meant only less advanced in the process of coal formation.

[b] Nos. 228, 230, and 237.

VARYING AVAILABLE HYDROGEN.

In Table 2 the proportions of hydrogen are shown both by means of its ratios with the oxygen in moisture-free coal, and as "available" hydrogen $\left(H-\frac{O}{8}\right)$. As might be expected, a number of the large errors seem to be explained by the relatively very large or very small percentage of hydrogen. Yet the evidence is not free from conflict, since in numerous analyses a high available hydrogen is shown without any corresponding error of excess calories; in others calorific excess attends a relatively low hydrogen. As coals in which the excess of calories would seem to be due to high hydrogen, citation may be made of Nos. 7, 21, 33, 36, 43, 52a, 86, 126, 168, 208b, and 247. Compare also Nos. 23, 38, 51, 53, 79, and 130. Several of the coals cited, however, are very low in sulphur, which, by reducing the amount of the negligible constants, enlarges the space for the other elements, especially carbon, and so promotes a higher efficiency for the fuel. There are on the other hand but few samples in which the lack of hydrogen seems clearly accountable for deficiency of calories. Probably of this sort are Nos. 19, 106, 112, 135a, 144, and 246. The low curve efficiencies of Nos. 163, 181, 190, 206, 211, and 236 are also possibly due to low hydrogen, though in these coals (marked "S" in Pl. I) which are undergoing anthracitization the volatile carbon likewise is very low; and since, in some of the advanced coals, an abnormally low volatile carbon appears to be a cause of calorific deficiency, it is possible that most of the coals last cited may be impaired by loss of volatile carbon as well as of hydrogen.[a] Outside of the semianthracites and more advanced semibituminous coals there do not seem to be many coals in the tables whose lack of calories is possibly traceable to low hydrogen. In Nos. 84, 93, 110a, 171c, and 196, the calories are high in spite of the low available hydrogen; while in No. 2b there is no available hydrogen at all, but on the contrary a deficiency of 0.37, yet the efficiency-curve error is but 150 calories. High efficiency with a relatively low available hydrogen is a common characteristic of the unweathered younger and less altered coals, in which the diluent sulphur is low. It is to be remembered that the efficiencies and errors here discussed relate to the ratio curve, and not to those calculated from Du Long's formula.

The number of coals in which a relatively high available hydrogen or H:O ratio is attended by a calorific deficiency, instead of excess, is surprisingly large. Examples are Nos. 27, 48, 56, 105, 138, 203, 215, 228, 237, and 238. (See also Nos. 40, 74, 76, 153, 158, 162, 164, 178, 185, 197, and 215.) Several of these coals have high sulphur, whose double effect is not fully overcome by the relatively high

[a] The relative values of both VC : C and H : O in the coals are better shown in Plate III than in Table 2.

hydrogen, as will presently be illustrated. Samples Nos. 228, 237, and 238 have abnormally low volatile carbon and very low oxygen; to the former the deficiency is probably due.

On the whole it may be said that while high available hydrogen tends to cause curve variances on the side of excess, there are comparatively few coals in which its effects are not so far neutralized by a high sulphur content, or (in case of very low sulphur) by an enlarged proportion of carbon or, perhaps, by a very high ash (Nos. 27 and 65), as to reduce the excess error to less than 100 calories. There appear to be 10 coals whose excess error of over 100 calories seems more or less distinctly due to the high available hydrogen. For the cannel-boghead group, whose hydrogen is characteristically greatly in excess, a higher curve should be drawn. The average total hydrogen in the 319 air-dried samples in Table 1 is 4.92 per cent.

SULPHUR.

In many respects sulphur is the most important of the neglected elements affecting the accuracy of the ratio-efficiency curve. Although the errors on account of this ingredient are generally slight, usually less than 1 per cent of the calorific value, its effect is no doubt relatively important in many cases.

In combustion the heat values of sulphur are generally recognized as depending on the state or condition in which it occurs. As free sulphur it is comparatively harmless and may exert its full theoretical calorific efficiency; in pyrite, marcasite, or other sulphides, its heat contribution is greatly lessened by the fact of combination, and also differs with the surrounding conditions; in sulphates, whether infiltrative, interstitial, or in the form of scales in the joints and cleavage planes of the fuel, it is a dead load to be borne at the expense of the other fuel elements. Unfortunately information as to the state of the sulphur in the samples tested and analyzed is unavailable for this report;[a] so that I am obliged to ignore the differences in the effects of the different kinds, and regard only the apparent influence in general and as a whole when the sulphur is in large or exceptionally small percentages.

Since the efficiency of the coals is very closely controlled, as has been shown, by the balance between the carbon and the two chief anticalorific elements, oxygen and ash, the sulphur, as well as the nitrogen and hydrogen, has in the preceding pages been treated as constant. But as a matter of fact, while the hydrogen and nitrogen appear to be constant in kind, differing only in quantity, the sulphur differs greatly both in quantity and in kind or effect. In the series of analyses shown in the tables the sulphur ranges, on the air-dried

[a] In most of the high-sulphur coals of the Eastern Interior basin the sulphur is probably chiefly in the form of sulphides.

basis, from a minimum of 0.22 per cent in No. 52b from Wyoming, to a maximum of 8.33 per cent in No. 138 from Kansas. Its average percentage in the 319 coals is 2.13.

Since sulphur even in its best condition has a smaller calorific value than carbon, it is plain that any unusually high percentage of it, unless compensated by increased available hydrogen, another of the constants, virtually dilutes the combustible of the coal and causes a falling off in its efficiency. Therefore a comparison of the analyses in the tables with reference to sulphur is necessarily chiefly confined, since we are not cognizant of the state of the sulphur in each sample, to the diluent effect in some of the coals of an abnormal proportion of this inferior combustible, and the effect of comparatively low sulphur in others. Accordingly, the practical and main purpose of the study is to observe the amount of the error or variance from the ratio-efficiency curve in consequence of unusual fluctuations in the sulphur percentages. As examples in which deficiencies in ascertained calorific value, as compared with the curve indications, are probably due to unusually high sulphur, may be cited Nos. 48, 65, 76, 80, 94, 96, 102, 138, 157, 185, 230, and 237 in the table. The errors in most of these cases are, however, small. The diluent effect of a difference in sulphur may in many coals be roughly approximated by rating the unit sulphur effect at the difference between its theoretical value (2,250) according to Du Long's formula and the calorific value of the unit of the rest of the coal which it partly displaces. The effect of the available hydrogen variation may be calculated at 34,460 according to Du Long's formula.

In passing down the columns it will be noted that as a rule the coals that are high in sulphur are also relatively high in hydrogen, the highest percentages of the former being usually attended by the greatest excesses of the latter.[a] The general result is the neutralization of the bad sulphur effect by the high hydrogen. In many cases the effect is converted from a deficiency to a small excess. As illustrating analyses in which the sulphur effect is not fully neutralized, comparison may be made of Nos. 9, 11, 16, 28, 40, 48, 55, 58, 63, 73, 74, 92, 105, 113, 138, 142, 143, 164, 178, and 203. Some of these are coals with the highest available hydrogen. Two of the most striking are No. 138 from Kansas and No. 203 from Missouri. Other instances of complete neutralization are Nos. 14, 20, 23, 33, 36, 38, 43, 48, 53, 69, 66, 79, 82, 98, 99, 147b, 153, 167, 168, 172, and 205. On the other hand, it will be noted that the coals with very low sulphur are more often accompanied by a low available hydrogen.[b] Some of the larger efficiency errors on the side of excess are coincident with the exceptional cases of very low sulphur and unusually high hydrogen. Examples are Nos. 21, 52a, 81a, 86, 93, 100, 118, 126, 128, 141, and 161a;

[a] Examples are Nos. 14, 20, 23, 40, 42–44, 45, 48, 49, 65, 66, 79, 82, 147–149, 153, 185, 187, 203, and 205.

[b] This applies to the Cretaceous and Tertiary coals in the tables.

also Nos. 31a, 134, 134a, 171a, 173b, and 179a. These fall for the most part among the Cretaceous coals, and their superior efficiency is probably connected with the high content of resin.

The review of the analyses with respect to sulphur shows, in general, that except among the fuels approaching anthracitization the the coals with highest sulphur usually have the highest available hydrogen, those with lowest sulphur being usually relatively low in hydrogen; and accordingly that in most cases the effect of an excess of sulphur is nearly counterbalanced by the presence of an excess of hydrogen. Conversely, the effects of unusual proportions of hydrogen are, in general, largely neutralized by a parallel variation in the sulphur contents of the coal. These facts explain, in most cases, the smallness of the ratio-efficiency curve errors in the presence of the greater variations of the available hydrogen. The mutually neutralizing action of the sulphur and hydrogen is the main circumstance making it so readily practicable to treat these elements as negligible in forecasting the efficiency of the coal solely on the basis of the carbon, oxygen, and ash. It should be noted that compensating the oxygen for loss with sulphur of pyrite (see p. 42) would by lowering the C:(O + ash) ratio tend to reduce the prevailing errors of deficiency in high-sulphur coals, while slightly reducing the available hydrogen.

NITROGEN.

Of this, the third and last of the neglected constants, I have not attempted a careful study with reference to error influence. From a casual inspection of the tables I am inclined to regard it as largely eliminated from the peats at an early date in the dynamochemical process, the remainder being, perhaps, mechanically retained in a free state, or in an unknown state of combination in the more advanced coals. It seems to be practically passive, and of so little range in amount as usually to produce no marked effect as a diluent. Its average percentage in Table 1 is 1.21. The study of the effect of nitrogen on the calorific values requires a series of analyses including larger groups of peats and of the succeeding low grades of coals.

ANTHRACITIZATION.

Both the greatest individual error and the greatest average variance from the curve are found among the highest of the semibituminous coals, which are undergoing anthracitization or in the anthracitic group itself. A glance at the percentages of fixed carbon in pure coal in Table 2 shows that nearly all the coals that have a fixed carbon of 79 or more are deficient in calories unless they have a high volatile carbon (see the VC:C ratios). The maximum variance among the 312 coals of the table is in the anthracite culm at Scranton, which shows a deficiency of 312 calories from the curve. In many of these

coals the deficiency is probably due to loss of hydrogen, as shown in the available hydrogen column of the table.

Of the 18 coals with as much as 79 per cent fixed carbon and a volatile carbon ratio of 9.25 or less, only 2 show excess errors. These 18 coals (excluding the Rhode Island semigraphite, which is not a fuel) are here grouped for better comparison:

Variance from curve efficiency of coals high in fixed carbon and low in volatile carbon.

No.	Locality.	Variance from curve.	Fixed carbon in pure coal.	Ratio VC to C.	Available hydrogen.	Sulphur.
		Calories.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
163	Scranton, Pa	−312	91.09	1.13	2.30	0.77
179	Spadra, Ark	−214	87.01	2.93	3.01	2.14
140	Blacksburg, Va	− 33	86.89	3.20	3.10	.66
162	....do	−115	86.50	4.48	3.49	.70
211	Coal Hill, Ark	−270	85.18	4.65	3.50	2.01
242	Panama District, Ind. T	−185	84.29	6.58	4.07	1.24
239b	Johnstown, Pa	−147	83.89	5.82	3.67	2.29
239a	Paris, Ark	−252	83.34	6.65	3.61	2.85
30	Gary, W. Va	+ 12	82.87	6.02	2.83	.55
238	Lloydell, Pa	−115	82.27	7.49	4.16	1.55
236	Bonanza, Ark	−250	81.92	7.96	3.73	1.90
228	Seward, Pa	−224	81.41	7.74	4.28	2.96
190	Georges Creek, Md	−106	80.94	9.02	3.42	1.51
161	Menlo, Ga	+163	80.57	6.73	3.39	1.31
181	Arkansas	−215	80.45	9.15	3.26	1.68
206	Midland, Ark	−230	80.36	7.64	3.50	2.12
237	Wehrum, Pa	−133	79.77	9.11	4.20	3.88
230	....do	−150	79.23	9.07	4.02	4.06

The average error for the 8 semianthracites, with fixed carbon of 83 per cent or more in pure coal, is 191 calories. The average error for the 10 highest-grade semibituminous, having a fixed carbon of over 79 per cent and a VC:C ratio (per cent) of 9.25 or less, is 158 calories. If this list of 18 coals be excluded from the table list the average error of the ratio curve is but 60.09 calories.

Other high-grade semianthracites which show calorific deficiency incidental to loss of volatile are the following:

Variance from curve efficiency of coals high in fixed carbon.

No.	Locality.	Variance from curve.	Fixed carbon in pure coal.	Ratio VC to C.	Available hydrogen.	Sulphur.
		Calories.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
212	Kimmelton, Pa	− 92	79.91	9.42	3.55	2.09
123	Huntington, Ark	−100	79.66	9.40	3.36	1.14
182	....do	− 60	79.25	10.00	3.41	1.27

The last sample has a higher volatile carbon. The VC:C ratios are better studied in Plate III, in which the coals are arranged in the order of their fixed carbon in pure coal (ash and moisture free).

On the other hand, among these coals approaching devolatilization it is interesting to note signs that a relatively large proportion of carbon in the remaining volatile is favorable to a higher efficiency. For

illustration: The coal at Sun, W. Va. (No. 240), with a relatively high volatile carbon (VC:C = 10.68 per cent) shows an excess of about 136 calories over the curve, though its available hydrogen, 3.65, is 0.45 below that of most of the coals near by in the series.[a] Relatively high volatile carbon probably assisted low sulphur in Nos. 213, 196, and 70, among others. Contrariwise, in Nos. 162, 228, 237, and 238 low efficiencies accompany unusual diminution of the volatile carbon, in spite of the fact that the available hydrogen is fully up to or above the normal in these coals. Possibly sulphur may have exercised a depreciating influence in Nos. 228 and 237.

These observations seem to indicate that although the calorific values in the lower grades of coals do not seem affected by the relative amount of fixed carbon, too great a loss of volatile carbon impairs the efficiency of the fuel.

The range of error in the determination of the fixed carbon in a coal forbids basing too confident conclusions on a limited number of observations.

WEATHERING.

The changes of coal under exposure or weathering are indicated in the analyses by reduced H:O ratios; by reduced available hydrogen; and in many cases by reduced volatile carbon ratios. Illustrations will be given later (p. 63) of these changes, invariably showing calorific deficiencies except in the high grades of coal. As a matter of fact weathering can in most cases be detected by the changes in the oxygen-hydrogen relations and by the marked calorific deficiencies.

QUANTITATIVE RELATION OF OXYGEN TO COKING.

SUPPOSED ALGAL INGREDIENTS IN COALS.

SOURCE AND CHEMICAL EFFECTS.

As stated in the introduction to this paper, one of the purposes of this comparative study was to ascertain the testimony of the ultimate chemical analyses as to the validity of a previously conceived working hypothesis in explanation of the coking property of coals. A few words will outline the basis of this hypothesis:

The brilliant investigations carried on by Renault[b] and Bertrand[c] as to the microscopical structure of a considerable number of bog-heads and oil shales of various continents and geologic ages show that these rocks owe their peculiar physical and chemical characters (which include a relatively high percentage of volatile matter, a

[a] The estimate of calorific value calculated from the chemical analysis of this coal was 312 calories less than the ascertained efficiency. See Prof. Paper U. S. Geol. Survey No. 48, 1906, p. 255.

[b] Renault, B., Les micro-organismes des combustibles fossiles, St. Etienne, 1903.

[c] Bull. Soc. d'hist. nat. Autun, vol. 9, 1897, p. 193; Trav. et mém. de l'Univ. de Lille, vol. 4, No. 21, 1898; Compt. rend. 8me sess. Cong. géol. internat., 1901, p. 453.

generally high illuminating value, etc.) primarily to the presence of immense numbers of supposed gelatinous algæ which in these coals seem to have exercised a selective attraction for certain bituminous compounds. Algal matter in smaller proportions, and consequently with less distinct resultant characteristics in the coal, is found also in the "cannel-bogheads" and some of the "boghead-cannels." The conditions of accumulation and deposition attending the origin of many other coals were doubtless favorable for the mingling of algæ and different animal remains in varying quantities with the débris of higher plant types; though their preservation, at least in optically recognizable form, is most improbable in any but the rarest instances. Yet it is more than probable that the substances of these lower organisms, whether completely macerated and disorganized or not, contributed as ingredients to the mass of coal-forming material. It is therefore reasonable to admit that though not optically discernible now, or though all their original structure is obliterated, they have probably exerted some influence on the character and quality of the final converted organic residuum.

It is not important to discuss in this place either the source proposed by the French paleobotanists for the bituminous "enrichment" of the coal or the time of the bituminization, though, for my part, I am disposed to regard the enriching bitumen as derived from the decay of associated animal organisms, as well as from the putrefaction products of great quantities of the gelatinous algæ themselves. The relatively increasing importance of the bituminous matter in the more mature, older, or more altered condition of the fuel is due, I believe, to concentration as the result of devolatilization and reduction of the coal by the dynamochemical process, the larger part of the concentration being the result of loss of oxygen, which is in larger proportion at the outset. The oxygen loss is disproportionally great as compared to that of the hydrogen. The liquid putrefaction products of the algæ must almost certainly have entered into the groundmass of the coal and participated in the infiltration of the immersed structural vestiges of higher and more enduring types of vegetation. The progressive deoxygenation of the organic matter effects a concentration of the bituminous compounds in the body of the organic material which is undergoing the processes of coal formation; that is, it accomplishes bituminization. However, the important point, so far as we are at present concerned, is the connection, as described by the distinguished French paleobotanists and later virtually corroborated by Potonié,[a] of these gelatinous ("sapropelic" of Potonié) elements with a highly bituminous quality of the fuel.

[a] Jahrb. K. preuss. Landesanstalt u. Bergakad., vol. 25, 1907, pp. 342-368.

CHARACTERISTICS OF ALGAL COALS.

We have next to note the following circumstances: (1) It will be seen on consulting the ultimate analyses published by the French paleobotanists that these algal (gelosic or sapropelic) coals are relatively high in hydrogen and low in oxygen, as is to be expected of coals that are tinged with the character of bitumen; (2) I have observed that those fuels, especially if Paleozoic and consequently more altered, are apt to fuse and even to swell on burning.

POSSIBLE CONNECTION WITH COKING QUALITY.

Now, these qualities, fusibility and swelling, concurrent with bituminization, which appear generally to characterize fuels known to contain recognizable quantities of gelatinous micro-algæ, are also necessary to the coking quality in coals. It is permissible, therefore, to inquire whether the coking property may not be due, at least among coals relatively low in fixed carbon, to some unascertained but not improbable proportion of gelatinous algal (sapropelic) matter entering into the original ingredient mass from which the coal was formed, and either directly or indirectly imparting to it this fusibility and tendency to swell.

Micro-algal ingredients, sometimes forming layers of considerable thickness, are recognized in peats, and their presence, occasionally in great numbers, has already been noted in a number of remarkable brown coals which have not been altered so far as to preclude satisfactory microscopical examination. Yet the detection by means of the microscope of such minute and delicate organisms as the algæ described from some of the bogheads and cannels, even if vestiges happened to be preserved, in coals so highly changed by the dynamochemical process as the coking coals, is a matter so difficult as perhaps to justify consideration as improbable. Being apparently barred at present from satisfactorily determining their presence by direct mechanical means, we are therefore left to search the evidence of the chemical analyses.

Not only does it appear that among coals of the same degree of progressive devolatilization those with the greatest amount of recognizable micro-algæ show hydrogen and oxygen most nearly in the proportions shown in bitumen, but in general it also seems, conversely, that those normally sedimented coals whose ultimate analyses approach most nearly to that of bitumen bear the more distinct microscopical evidence of the presence of the algæ. The coals whose large volatile combustible matter contains relatively the highest hydrogen and the lowest oxygen, thus approaching nearest the bitumen analyses, are those in which the organic remains described as micro-algæ are most predominant and often best preserved.

Of the following analyses No. 1[a] represents the Torbane Hill boghead; No. 2,[a] the Kerosene shale (Permian) of New South Wales; No. 3,[b] a hard pitch; No. 4,[b] "pitch E," used in briquetting tests.

Analyses of algal coals approaching bitumen and of pitches.

No.	S.	H.	C.	O+N.	Ash.	Moisture.
1	.....	8.50	65.44	3.44	22.62	.....
2	.....	9.63	76.61	2.87	10.04	.....
3	0.88	4.56	90.34	3.06	1.16	0.33
4	.66	4.22	91.30	2.99	.83	1.02

The tentative inference that sapropelic matter and the bituminous concentration[c] have a direct connection in these high-volatile coals is, I believe, quite justified.

If the inference is correct that in the high volatile coals high bituminization (concentration of bituminous substance) and gelatinous algal (or sapropelic) ingredient elements go together, and if the observation of the connection between the presence of the latter (and consequent bituminization) with the tendency of the coal to fuse and swell is well founded, it seems probable that such coals of high bituminization will contain algal elements and (what is more important) fuse on burning in the mass. In other words, we may conclude that high volatile coals whose analyses show sufficiently high bituminization will coke by the ordinary process. The degree of bituminization in these coals is indicated by the relative excess of hydrogen as compared with the diminished oxygen in dry coal. It is expressed by the ratio H:O.

HYDROGEN-OXYGEN RATIOS OF COKING COALS.

DESCRIPTION OF DIAGRAM IN PLATE III.

The test of this working hypothesis lies in the examination of the H:O ratios, dry-coal basis, of the coals with reference to the known behavior of the fuels in coking tests. The data essential to the study of the analyses for this purpose are set forth in diagram in Plate III. Sulphur is omitted from this diagram because it does not seem to influence the coking quality of the coal, though of course greatly affecting the quality of the coke from the metallurgic standpoint. Ash also is omitted as not essential to the comparison.

In this diagram all the coals are rearranged in the order of their fixed carbon percentages (F. C.) in pure coal, as given in Table 2, and

[a] Renault, B., Les micro-organismes des combustibles fossiles, p. 149.

[b] Prof. Paper U. S. Geol. Survey No. 48, pp. 266, 267.

[c] The gradual development of distinctness in the chemical resemblance to bitumen as progressive devolatilization eliminates more and more of the oxygen is essentially mere concentration. I therefore employ this term in place of enrichment, which suggests that bitumen has been brought in from some source entirely outside of the bed of coal.

with the same numbers. This order is chosen as conforming, to some extent, to the evolution of the coals. It is genetic in so far as it shows the progressive devolatilization of the coals—that is, the progress in their dynamochemical alteration or improvement.

In order to present the additional essential criteria in a simple and graphic arrangement for comparison, the hydrogen-oxygen ratios are platted as heavy continuous lines extending to the right, and the ratios of volatile carbon to carbon (VC:C) are platted as heavy broken lines extending to the left, from a point representing nearly complete devolatilization. In the figure columns both these ratios are expressed as percentages. For comparison with the H:O ratios the available hydrogen has also been platted as light broken lines extending to the right.

The annotations as to coking, at the right, are mainly those based on the tests by the United States Geological Survey and kindly furnished by Mr. J. S. Burrows, chief inspector. Information from other sources has been incorporated regarding some coals not tested for coke by the Survey.

INDICATIONS OF RATIO LIMITS.

The evidence of the hydrogen-oxygen ratios as to the coking quality of the coals needs no extended discussion. A review of the wide fluctuations in the H:O ratios, together with the annotations as to coking, strongly indicates, so far as the tests have been made or the information is at hand, that, below the highest of the semibituminous coals which are approaching anthracitization, those coals with a H:O ratio (percentage) of 59 or more, with but one or two exceptions, make coke by the ordinary commercial process. Nearly all those below 59 and above 55, so far as tested, make a coke, and among those ranging down to a ratio of 50 a large percentage coke, while one or two of the tested coals coke at a slightly lower ratio. It would seem, however, that the cokes made from those coals with a H:O ratio less than 55 are usually very poor and apt to be brittle and dark.

It appears, therefore, that among coals which are not too far devolatilized practically all that are sufficiently bituminized—that is, have a H:O ratio of 59 or over—are almost certain to possess the coking fusibility, and that coke of good quality may usually be expected from coal with a ratio as low as 55, while very poor results may be obtained when the ratio is as low as 50. The best cokes obtained by the ordinary process are made from coals having a ratio of 60 or over.[a] In the H:O ratios of Table 2 and Plate III no oxygen compensation is made for sulphur in pyrite.

[a] The coking tests made by the United States Geological Survey are based on the ordinary beehive-oven process.

	$\frac{VC}{C}$ %*	Remarks.	No.
	67.46		4a
	54.09		1
	52.52		6
	44.29		7
	42.03		9a
	41.15		3
	39.21	No coking test	147b
	35.20		11
	36.17		8
	32.32		2
	32.62	Distilled for oil	4
	36.69	No coking test	20
	35.68	Makes brittle coke	63
	29.66		12a
	29.78	Burned to ash	9
	30.95		51a
	38.62	Cokes fairly well	203
	32.36	No test	18
	30.00		19
	32.93		41
	33.12		57a
	17.47		2b
	36.16	Makes coke	52a
	33.29	No test	56
	33.55	Good hard coke on Ill.7D	26
	29.67		5
	32.27		25
	34.75	No test	153
	33.73	Small pieces of coke in test	61
	32.96	Poor hard and soft coke	14
	28.40		13
	31.40	Cokes fairly well	51
	28.85		44a
	33.29		17
	32.62	No test	99
	32.75	Good heavy coke	105
	32.15	Hard coke on Ill.7D	49
	31.02	No test	69
	31.26	No test	55
	32.70	Cokes	52
	31.23	No test	66
	34.93	Soft dense coke in test	184
	33.71	No test	67
	30.56		83
	31.79	No test	81
	33.83	Fair though brittle coke	142
	33.49	Good light-gray silvery coke	80
	30.85	Coked in small pieces	48

* H over 2.7.

	VC/C % *	Remarks.	No
	30.74		52b
	31.80	No test	120
	28.50		33a
	27.29		22
	32.09	No test	74
	31.75	No test; is coked	87
	32.48	Cokes well	149
	32.05	No test	43
	29.61		32
	30.54	No test	73
	31.77	Makes good coke	98
	27.94		55a
	32.18	Good but very brittle coke	109
	28.22		73c
	29.82	Poor soft, dense coke	38
	31.89	No test	168
	30.85	No test	113
	28.47		31
	29.17	No coke on test of Ill.25A	53
	30.60	No test	76
	31.41	Good heavy coke	107
	29.28	Small pieces of coke from test	10
	29.45	Coked	94
	30.22	No test	42
	30.33	Good coke of good weight	90
	29.79	No test	15
	31.59	Said to coke well	130
	28.41		66a
	30.95		2a
	29.18	Coked: light gray	45
	32.20	Good coke	172
	29.73		81a
	29.17	No test	28
	25.29		24
	31.87	No test	117
	29.46	No test	62
	31.21	Fair coke; light-gray silvery	102
	28.02	Cokes; hard but brittle	138
	29.90		110a
	31.31	Good but brittle coke	154
	28.61	No tendency to coke on test	16
	30.04	Good coke, metallic ring	91
	30.24	Coke soft, poor on test	92
	29.84	Poor dull-gray coke	82
	27.96	No coke from test	40
	28.53	No test. Ill. 29 poor coke	57
	23.80		53a
	27.58	No test	12

e H over 2.7.

	$\frac{VC}{C}$ % *	Remarks.	No.
	27.89	No test	50
	27.62	No coke produced	75a
	32.16	Good coke, somewhat brittle	205
	26.80	Poor, dense coke	59
	29.64	Fairly good coke	111
	29.86	Unsatisfactory test	137
	25.95		52c
	27.62	No test	73
	27.81		12a
	30.67	Said to make coke	175a
	26.87	No coke from test	96
	29.63	Good coke, metallic ring	108
	27.75		73a
	23.37		39a
	26.07	Poor, dense coke	33
	25.85		84a
	27.37	No test	46
	29.57	Good coke	167
	27.33	Said to be noncoking	31a
	30.64	Very brittle, dense coke	128
	27.87		146b
	28.60	Said to coke well	131
	25.56		75b
	28.82	Good coke	129
	30.11	Once coked commercially	132
	28.86	Burned to ashes in test	77
	30.37	Fine heavy coke	178
	27.10		64
	26.49	No coke from test	144
	29.39	Good but brittle coke	171
	31.05	Coked well	160
	27.73	Noncoking	28a
	24.13		46a
	30.08	Good coke; metallic ring	187
	20.49		39b
	27.16	No coke from test	70
	27.88	Fairly good coking	133
	25.66	Partially coked in test	36
	28.30	No test	39
	26.53	Poor dark-gray coke	75
	28.52	No test; said to coke	103
	26.03	Noncoking	147a
	27.78		173b
	28.79	Coke; medium cells	101
	27.03		171a
	27.96	No test	166a
	25.82		174a
	25.76		154a

over 2.7.

	$\frac{VC}{C}$ % *	Remarks.	No.
	31.26	Very good hard, heavy coke	215
	29.44	Coked well	126
	26.26		134a
	28.34	No coke from test	146
	29.45	Good heavy coke	118
	24.50	No test	29
	28.95	Coked	158
	24.34		37
	29.24	Cokes well	211a
	27.45	No test	171b
	23.65		146a
	30.57	Noncoking	101a
	24.33	No test	54
	25.24		179a
	26.04	Coke with poor structure	68
	27.49	Good coke	148
	26.70		160a
	27.29	No test	136
	23.19	No test	23
	25.46	No test	78
	26.62	No test	34
	28.75	Commercial coke	188
	27.74	Said to coke poorly	176a
	21.50	No test	44
	28.43	Said to coke well	125
	25.29	No coke from test	47
	29.53	Good coke	207
	28.30	No test; cokes well	100
	24.71	Makes brittle coke	60
	22.99	No test	58
	28.86	Poor dull-gray coke	71
	26.25	No test	110
	27.97	Good heavy coke	93
	29.30	Good coke	217
	27.27	Good but brittle coke from test	183
	27.75	Commercial coke	86
	24.56	Imperfect test	79
	25.42	No test	165
	22.76		161a
	29.31	Good coke	219
	27.06	Fair brittle coke	177
	27.24	Cokes well	164
	24.67	No test; said to coke well	135
	26.86	No test	115
	26.69	Imperfect test	143
	26.90	Makes good coke	157
	27.19	Good heavy coke	185
	28.75	Good hard, heavy coke	234

* H over 2.7.

	$\frac{VC}{C}$ %*	Remarks.	No.
	27.95	Good but brittle coke	224
	25.32	Cokes well	88
	26.75	Good but brittle coke	186
	25.45		173a
	25.00	No test	119
	24.99		171a
	25.13		208a
	23.84	Coked well	104
	27.17	No test; said to coke well	155
	26.14	Good strong, hard, heavy coke	156
	24.70	No test	112
	21.63		72a
	26.68	No test	215a
	25.27	Coked imperfectly	114
	27.11	Coked commercially	229
	24.73	Dull-gray coke	122
	24.35	No test	116
	27.45	Good coking coal	175
	27.51	Good coking coal	209
	23.86		149a
	27.03	Cokes well	199
	24.67	No test; strong coke on Ill. 11 D	170
	27.37	Very good coke	218
	27.34	Coked commercially	204
	24.60	No test	145
	27.30	Good heavy coke	141
	22.84		146c
	17.99		62a
	26.52	Good hard coke	221
	27.02	Makes good coke	220
	26.49	Good but very brittle coke	233
	25.63	No test; said to coke	208b
	22.19	No test	127
	26.55	Makes fine coke	169
	25.80	Good coking coal	192
	26.90	Fine coking coal	226
	23.33	Soft, dense, dull coke	85
	26.24	Cokes well	214
	20.80		136a
	25.56	Cokes well	159
	24.99	No coke from test	147
	26.09	Is coked	174
	22.08	No coke from test	84
	23.54	Said to coke	173
	22.71	No test	65
	23.09	No coke from test	95
	22.50	Poor brittle coke	97
	25.14	Good hard, heavy coke	201

* H over 2.7.

	$\frac{VC}{C}$ %*	Remarks.	No.
	22.94	No test	139
	26.52	Cokes well	242a
	25.32	Cokes well	216a
	25.88	Good hard, heavy coke	231
	23.67	Coking coal	231a
	22.19	Dark-gray coke; small cell structure	124
	21.77		135a
	24.37	Good coking coal	227a
	25.79	Good hard, heavy coke	222
	24.13	Good heavy coke	202
	23.35	Fairly good coke; large cells	180
	23.63	Said to coke well	210a
	19.16		73b
	23.62	Strong, hard, heavy coke	134
	24.56	Fine strong coke	166
	25.18	Fine coking coal	223
	24.42	Makes excellent coke	197
	21.13	No coke from test	106
	21.69	Very good coke	191
	17.71		44b
	24.31	Good heavy commercial coke	243
	22.46	Said to make good coke	208c
	23.31	Said to coke well	198
	15.09		25a
	22.80	Good strong, heavy coke	150
	23.83	Very good coke; commercial	245
	21.95	Commercially coked	89
	22.40	Makes a good coke	194
	21.74	Good coke	151
	21.83	Good heavy coke	176
	21.30	Good coking coal	189
	21.46	Makes good coke; high ash	200
	20.30	Excellent standard coke	196
	21.02	Coked commercially	232
	19.96	Good, heavy, silvery coke; metallic	121
	20.02	Good, hard, commercial coke	239
	20.89	Good coke with cross fracture	216
	19.12	No test	21
	20.65	Very good coke	208
	20.61	Very good coke	225
	18.97	Poor coke from test	27
	18.41	Heavy, light-gray silvery coke	235
	16.11	Dense coke from test	210
	12.94	No test. Said to coke	227
	15.14	Good coking coal	249
	13.69	Good heavy coke	193
	13.41	Makes good coke	231b
	13.26	Tough, dense coke; commercial	248

1 over 2.7.

	$\frac{VC}{C}$ %*	Remarks.	No.
	11.41	No test	195
	10.68	Good quality coke	240
	7.71	No coke from test	35
	9.07	Cokes in by-product ovens	230
	10.00	Soft, dense coke; poor cells	182
	9.40	Burned in test	123
	9.11	Soft dense coke in test; coked in by-product ovens	287
	9.42	Pieces of coke in charge on test	212
	11.63	Good hard, heavy coke	250
	7.64	No test. Test of Ark.7B produced no coke	206
	9.15	No test	181
	10.58	Good large coke	247
	11.06	Good coke	246
	6.73	Poor dense coke from test	161
	10.55	No coke from test; said to make good coke	213
	9.02	Poor soft coke	190
	9.49	Soft dense coke from test	244
	10.39	No test. Poor coke once shipped	241
	7.74	Soft dense coke from test	228
	7.96	No tendency to coke on test; burned to ashes	236
	7.49	No test	238
	6.02	No test; said to be coked	30
	6.65	No test	239a
	5.82		239b
	6.58	No test	242
	4.65	No test	211
	4.48	No test	162
	3.20	No test	140
	2.93	No test	179
	1.18	No test	163
	1.98	Not a fuel	152

* H over 2.7.

APPLICATION TO ALGAL HYPOTHESIS.

Applying these observations to our tentative hypothesis to account coincidently for both bituminization and fusibility, the conclusion that gelosic (or sapropelic) elements have entered into the composition of certain of the coals in the list seems justified. So far as the coals low in fixed carbon are concerned, I am disposed to regard it as essentially confirmed.

The Barnett, Mo., coal (No. 203) with a fixed carbon (pure coal) percentage of 49.76 and a H:O ratio of 94.9 I regard as most probably gelosic (sapropelic). So also with the coal from Sprague, Mo. (No. 43), with 53.55 fixed carbon and 79.4 H:O ratio, and Atchison, Kans. (No. 138), with 54.79 fixed carbon and 97.9 H:O ratio. I have not personally examined specimens from any of the above-mentioned coals. Provisionally, I am inclined to believe that small portions of gelosic matter probably entered into others of the coals whose ratio percentage is conspicuously above that of the associated bituminous coals having nearly the same percentage of fixed carbon, though lower than those mentioned. Among the most prominent of these mention may be made of Stone Canyon, Cal. (No. 147b), with 46.22 fixed carbon; Altoona, Iowa (No. 63), with 48.77; Hymera, Ind. (No. 80), with 52.87; Clarksburg, W. Va. (Nos. 205 and 215), with 55.71 and 58.28, respectively; Wilder, Tenn. (No. 158), with 58.50; Yale, Kans. (No. 79), with 59.91, and Clifty, Tenn. (No. 164), with 60.08. If an unknown, probably very small, amount of gelatinous algal matter entered into the composition of these coals, it probably has been optically obliterated, if not quite macerated. In passing it may be remarked that the provisional hypothesis appears to harmonize in all respects with the tendency of the coking coals to cohere when reduced to a fine powder under the pestle, discovered by Max Pishel[a] since the preparation of these tables.

COKING OF HIGH FIXED CARBON COALS.

VOLATILE-CARBON RATIOS.

The reader will have noted in passing down the H:O ratio columns in Plate III that after reaching a fixed carbon in pure coal of 66 or 67 per cent, H:O ratios of 60 per cent or over characterize all the coals. Accordingly it should follow that all these coals possess the fusing quality and are susceptible of coking. This is practically true, for it appears that nearly all the coals in this portion of the list will coke up to a fixed carbon of about 79 per cent, beyond which, as may be noted in the "remarks," some of the coals do not coke well by the ordinary

[a] Econ. Geology, vol. 3, No. 4, 1908, p. 265.

process, while others apparently refuse to coke. A typical example of the latter kind is No. 35 from Bonanza, Ark., with 78.97 fixed carbon and a ratio of 73.7. Inspection of the columns of VC:C ratios shows that the high fixed carbon coals which apparently are noncoking are relatively low in volatile carbon, while certain other coals with a fixed carbon as high as 80 are said to coke well, although sometimes with considerable waste of uncemented carbon. The volatile of these high fixed carbon coking coals, it will be observed, seems to be characterized by a relatively high proportion of carbon. According to the tests, and so far as the present series of analyses illustrates, it would seem that coals of over 79 per cent of fixed carbon in pure coal can not be depended upon for coking by the ordinary process if the volatile carbon to carbon ratio (VC:C) is less than 10 per cent. Several of these highest-grade semibituminous coals, which are approaching the semianthracite group and whose volatile carbon ratio is less than 10, are said to give good results in by-product ovens. An example is No. 237 from Wehrum, Pa., in which the fixed carbon is 79.77 per cent and the VC:C ratio 9.11 per cent.

CONSULTATION OF EFFICIENCY ERRORS.

Another method of distinguishing the coking from the noncoking coals in this group with over 78 or 79 per cent of fixed carbon, more practical and perhaps more reliable than observation of the volatile carbon ratios, is consultation of the efficiency errors, for the examples before us seem to indicate that the highly developed coals which do not possess the coking quality show very marked deficiency errors. This is well illustrated by the analyses of the higher semibituminous and the semianthracite fuels from Arkansas.

HYDROGEN AND OXYGEN LOSSES IN THE PROGRESSIVE DEVELOPMENT OF COAL.

An explanation of the general upward progress of the hydrogen-oxygen ratios in coals of over 66 per cent fixed carbon (all such in the tables being high) may be found in the more unequal rate of loss in the hydrogen and the oxygen during the more advanced stages of the progressive devolatilization of the coals. Observation of the relative loss of hydrogen and oxygen in the different groups of coals (dry-coal basis) shows that the curve of the hydrogen, though inclined steeply at first in passing from cellulose and lignose through the peats into the lignites, grades very gently through the great body of subbituminous, bituminous, and lower semibituminous coals, but pitches more rapidly near the semianthracite rank. The oxygen curve, on the contrary, exhibits a much steeper gradient, dropping

through a much wider range, while passing through the subbituminous and bituminous coals; but before reaching the semibituminous coals it begins to decline more rapidly than the hydrogen curve, and this acceleration continues, so that in many coals the oxygen percentage, as will have been noted, becomes considerably less than the hydrogen. Examples are Nos. 179, 190, 193, 211, 212, 213, 228, 230, 231b, 236, 237, 239a, and 239b. This relatively accelerated loss of oxygen as compared with that of hydrogen is expressed in the increase of the ratios.

AVAILABLE HYDROGEN AS INDEX OF COKING COALS.

I have been very greatly interested since the completion of the first draft of this table in December to learn from my chemical colleagues of the well-known hypothesis of the dependence of the coking principle upon the relative amount of available hydrogen. This method of determining from the ultimate analyses whether coals will coke, which has been discussed by Percy, is said to apply successfully in certain areas and groups of coals, though in other groups and regions it is regarded as a failure.[a] On account of the unusually wide range in age, kinds, and characters of the coals represented in the accompanying tables, it has been very interesting to compare the available hydrogen with the observations as to the coking quality. In the column to the right in Table 2 will be found the available hydrogen of all the coals. The same data are transferred, with their corresponding numbers, to Plate III, in which they are platted as light broken lines. Examination of the hydrogen percentages in this table shows that while they tend to parallel the H:O ratios there are many variances, because in general high total hydrogen means high available hydrogen, but not necessarily a high ratio with oxygen.

The diagram shows that while practically all the coals with an available hydrogen of 3.80 or more will coke well unless they are too high in fixed carbon, some good cokes result from fuels with less than 3.50. Several of the tests show cokes from coals with as low as 3.20 available hydrogen. Note the following examples:

Coking coals with low available hydrogen.

No.	Fixed carbon.	Available hydrogen.	No.	Fixed carbon.	Available hydrogen.
10	54.07	2.63	85	62.31	3.13
14	51.38	3.05	124	63.76	3.29
26	50.89	2.99			

[a] For discussion of the relation of the available hydrogen to the coking quality, see Fulton, John, Coke: a treatise on the manufacture of coke and other prepared fuels, and the saving of by-products; Scranton, 1905, pp. 31-38.

Other coals with much higher available hydrogen fail in the tests, as shown in the following examples:

Noncoking coals with high available hydrogen.

No.	Fixed carbon.	Available hydrogen.	No.	Fixed carbon.	Available hydrogen.
31a	56.87	3.30	147a	57.95	3.40
40	55.16	3.32	236	81.92	3.73
96	56.42	3.42			

This method also breaks down in the highest semibituminous coals. The loss in volatile in most of the coals of that category leads to a falling off in the available hydrogen. However, on account of the relatively more rapid oxygen loss in the higher coals the available hydrogen percentages sometimes persist after the coal refuses to coke, as in the Bonanza, Ark., coal (No. 236).

It may have been its failure as a coking index for the coals which are approaching semianthracitization at the Allegheny Front, in Cambria County, Pa., that led Fulton[a] to regard this method as of doubtful reliability.

HYDROGEN-OXYGEN RATIO THE BEST INDEX.

On the whole it is fairly evident that in coals of less than 79 per cent fixed carbon (in pure coal) the H:O ratios, dry-coal basis, offer surprisingly reliable, narrowly defined, and logical criteria for determining the presence of the coking quality from the ultimate analysis. It has also been noted that in the succeeding and higher coals coking is generally possible if the amount of carbon in the volatile is relatively large; also that most of the coals whose H:O ratio is high but which refuse to coke are clearly distinguished by their marked calorific deficiency with reference to the C:(O+ash) ratio and efficiency curve.

STATUS OF ALGAL HYPOTHESIS.

Since practically all coals in the table having fixed carbon contents of 66 per cent or over are found to show high H:O ratios, and possess the coking capacity thereby indicated, the provisional alga-element hypothesis can not be regarded as demonstrated by the ultimate chemical analysis; that is, it does not seem tenable to conclude that all of these coals fuse by reason of the presence of an alga-element. Yet the tentative hypothesis appears to have such strong support in coals of higher volatile that it commands respect-

[a] Fulton, John, Coke and coke making. Ed. 1905, p. 31.

ful consideration. It appears that in the course of the concentrations incident to progressive devolatilization, more rapid loss of oxygen brings about in the higher coals the same approach to bituminization (high H:O ratios) that in the lower coals resulted from the nature of the ingredient matter. That sapropelic influences, even in the higher coals, bear directly on the best coking results is not precluded from possibility. The conspicuous tendency of the recognized alga coals to preserve not only a high hydrogen but also a very high percentage of volatile carbon, may perhaps account for the persistence of relatively high carbon in the volatile, and for the apparently concomitant tendency to fuse, in some of the semi-bituminous coals which have fixed-carbon contents of 80 per cent or more. Examples of such high-volatile carbon coals are the following:

Coals high in fixed carbon, showing also high volatile carbon ratios.

No.	Location.	Fixed carbon.	VC:C ratio.	No.	Location.	Fixed carbon.	VC:C ratio.
241	Frostburg, Md	81.36	10.39	246	Big Sandy, W. Va	80.46	11.06
213	Zenith, W. Va	80.73	10.55	250	Mora, W. Va	80.15	11.63

MIXTURE OF COALS FOR COKING.

The data given in Plate III are rich in suggestions as to blending of coals in order to obtain either the best coking results,[a] or successful treatment of coals that refuse to coke well by the ordinary process. These suggestions relate not only to the mixing, according to the practicabilities of the regional trade conditions, of coals with relatively high H:O ratios and moderate fixed carbon, like that at Blossburg, N. Mex.,[b] with others whose ratios are hardly up to the standard for good fusion; but also to the mingling of certain coals high in fixed carbon with others rich in volatile matter—that is, high in hydrogen and carbon. For example, the high H:O ratios of the rich-volatile coals listed below promise mutually beneficial economies if finely ground and mixed with such coals high in fixed carbon as those in the second part of the table, more especially since in some of the latter there appears to be waste of fixed carbon when coked by the ordinary process.

[a] The sulphur and ash which so thoroughly control the market value of the coke are not considered in this discussion. For percentages of these, see Tables 1 and 2.

[b] See No. 141 (F. C. 61.49, H:O ratio 72.5); also Brilliant and Van Houten: No. 126 (F. C. 58.32); No. 118 (F. C. 58.48); No. 100 (F. C. 59.39), and No. 86 (F. C. 59.87). It would be interesting to note trials of coals such as No. 138, from Atchison, Kans. (F. C. 54.79), or Sprague, Mo., No., 43 (F. C. 53.55), or Hartshorne, Ind. Ter., No. 125 (F. C. 59.25) when comminuted and mixed for the ovens with some coals with lower ratios from the Rocky Mountain coal fields; though the sulphur and ash of Nos. 138 and 43 are too high for tolerance in commercial coke.

Comparison of two classes of coals suggested for mixing.

COALS RICH IN VOLATILE MATTER, WITH HIGH H:O RATIOS.

No.	Locality.	Fixed carbon.	H:O ratio.	No.	Locality.	Fixed. carbon.	H:O ratio.
		Per cent.	*Per cent.*			*Per cent.*	*Per cent.*
155	Creighton, W. Va.	60.77	83.7	193	Ligonier, Pa.	75.20	152.0
164	Clifty, Tenn.	60.08	106.1	205	Clarksburg, W. Va.	55.71	77.0
167	Bellaire, Ohio.	56.86	67.3	215	....do	58.28	101.9
169	East Millsboro, Pa.	62.26	85.4	222	Acme, W. Va.	63.88	100.6
172	Bellaire, Ohio.	54.55	67.4				

COALS HIGH IN FIXED CARBON.

30	Gary, W. Va.	82.87	93.0	228	Seward, Pa.	81.41	250.0
161	Menlo, Ga.	80.57	79.9	230	Wehrum, Pa.	79.23	215.2
212	Kimmelton, Pa.	79.91	125.5	244	Ehrenfeld, Pa.	81.28	149.8
213	Zenith, W. Va.	80.73	128.4				

It is possible that some of the coals last mentioned or some of those farther north in Pennsylvania might mix to advantage with some of the high-volatile and high-ratio coals of Michigan, the Lower Verne coal for instance.

GENERAL OBSERVATIONS ON THE TABULATED COALS.

RANGE OF THE SAMPLES.

A general view of Plate III shows the wide range of the coals which have been investigated by the United States Geological Survey. The ultimate analyses, standardized under the direction of N. W. Lord, include most of the commercial coals and extensive coal areas of the country.

RANK OF PEATS AND LIGNITES.

It is interesting to note that although the peats (Nos. 1 and 6, marked P), not having been subjected to the action of dynamochemical agencies, naturally gravitate to the foot of the scale of fixed carbon percentages, they are preceded in the scale by the Fort Union (Eocene) brown lignite from Glendive, which consists largely of a compressed accumulation of logs and sticks. The low fixed carbon of this coal is probably due to the lack of maceration or putrefaction previous to the development of antiseptic conditions. With the development of asepticity in a coal-forming mass, no further obliteration of the vegetal structures occurs except such as result from infiltration and compression (deformation). In the normal course of events the dynamochemical influences follow.

Following the peats are mingled brown coals (denoted by L) and subbituminous coals (S) more familiarly known as "black lignites." Interspersed among both of these types occur some of the lower grade

bituminous coals as recently classified by M. R. Campbell by their color and characteristics of weathering. Among the latter are several which, as we have already noted, appear to be somewhat gelosic (sapropelic), a relatively low fixed carbon being characteristic of that type of coal.

EXPLANATION OF HIGH OXYGEN.

Remembering that the hydrogen-oxygen ratios are based on moisture-free coal, the persistence of a relatively high oxygen content and consequently low ratio, even in certain of the coals of moderate fixed carbon, is striking. Excluding the coals that have taken up oxygen as a result of exposure or weathering,[a] the high oxygen of the low-ratio coals remaining in any group characterized by a definite fixed carbon may be explained either by (1) abundant natural charcoal, which has given the sample an abnormally high fixed carbon, or (2) differences in the original ingredients and conditions of deposition which have given the coal a chemical aspect approaching that of humic or ulmic acid, in contrast to the coals whose high H:O ratios give them a bituminous aspect.

QUANTITATIVE RELATION OF VOLATILE CARBON AND HYDROGEN.

One of the most significant features indicated graphically in Plate III is the relations suggested by the two sorts of volatile ratios. The rapid increase in fixed carbon in the peats and lignites at the beginning of the column is of course accompanied by a decrease in the volatile carbon, as expressed by the VC:C ratios. This decrease is nearly parallel to the decrease in volatile combustible matter which is the difference between the fixed carbon and "pure coal." But even before the lignites are passed over it is evident that to a certain extent a coordinate relation exists between the volatile carbon and the hydrogen. The coals whose hydrogen is relatively high as compared to the oxygen are seen almost invariably to have a high volatile carbon; so that the lines representing the two ratios tend conspicuously to approach or withdraw from each other throughout the greater part of the diagram. The Barnett (Mo.) coal (F. C. 49.76) shows this especially well, and evidently has a very large proportion of both hydrogen and carbon in the volatile. Presumably these two elements are largely in chemical union at the moment of escape. On the other hand the distant retreat of the ratios in the weathered coal from the Labarge Range (F. C. 50.63) shows most convincingly a great amount of highly anticalorific oxygen, evidently the overwhelming component in the volatile combustible matter.

[a] Coals with *a*, *b*, and *d* affixed to their locality, in Pl. III, are examples more or less affected by exposure.

LOSS OF VOLATILE MATTER.

Some points relating to the devolatilization of the coals deserve special notice. The relative decrease of the volatile-carbon ratios as compared to the increase in the fixed carbon column seems to be rapid in passing from 40 to 50 per cent fixed carbon. Above this the relative loss of volatile carbon is slight up to near 63, but still higher the loss appears slightly to accelerate; and in the coals having 70 per cent or more of fixed carbon the ratios seem to fall off a little more rapidly. The unusually low volatile-carbon ratios of the noncoking high semibituminous coals is well seen in the retreat of the VC:C lines for these coals in Plate III.

The falling off of carbon in the volatile of the higher coals is accompanied by a general decrease in the oxygen as compared to the hydrogen. The higher H:O ratios show that the volatiles are becoming richer in hydrogen and lower in oxygen in passing to the semianthracite group. At the same time, however, the amounts of available hydrogen fluctuate in marked reactions, though tending to hold their own fairly well from 65 to 75 per cent fixed carbon. Above this they react wildly, and on approaching the anthracites they decline rapidly, regardless of the H:O ratios. Yet, as I remarked in the discussion of the curve variance, the loss in calorific efficiency in the latter coals seems to me disproportionately large as compared to the loss of available hydrogen.

RELATION OF STAGE OF COAL FORMATION TO CLASSIFICATION.

LIKE ANALYSES FOR COALS OF DIFFERENT ORIGIN.

In passing down the columns of Plate III the reader will doubtless have noted that the middle-grade bituminous coals of the Cretaceous and Tertiary mingle with the lower-grade coals from the Eastern Interior basin, and are like them as to fixed carbon contents, H:O ratios, and relative volatile carbon. So it is also in the higher bituminous coals. There are in general no appreciable differences to be noted in the ultimate chemical analyses. In illustration of this fact, attention may be called to the agreement in fixed carbon, hydrogen-oxygen ratios, and volatile-carbon ratios, as well as in the actual percentages of composition, between such coals as those from the Raton-Trinidad district[a] of upper Cretaceous age, and the high-grade eastern, Paleozoic coals with which they are associated in the table; or, to cite a specific illustration, between Van Houten, N. Mex. (No. 86, F. C. 59.87) and Rush Run, Ohio (No. 183, F. C. 59.79), or

[a] Allowing for low sulphur in the western coals here mentioned. See No. 141 (F. C. 61.49), No. 199 (F. C. 61.23), and No. 100 (F. C. 59.39).

Darby, Va. (No. 217, F. C. 59.60). In the lower grades of bituminous coals the Cretaceous and Tertiary samples apparently have slightly higher volatile-carbon ratios as compared with the H:O ratios than the Paleozoic coals of the same rank. This may be due to the amount of resin in most of the former. Under advanced devolatilizing influences the resin appears to be transformed, possibly to disappear in the volatile.[a]

DISTINCT CATEGORIES IMPOSSIBLE.

Plate III in connection with Table 2 conclusively shows the futility of looking in the ultimate analyses for characters by means of which coals may be grouped into distinct and natural categories. Such a classification is an impossibility with only the current data. There are no distinct lines of separation of coals into any categories. From the very circumstances of coal formation—the constantly varying ingredients, conditions of accumulation and deposition, and relations and intensities of the processes—it is evident a priori that between each type and any other type there must be, since coal is merely a mixture of chemical compounds, every degree of intergradation. The classification of coals on the basis of their chemical analysis must therefore be absolutely arbitrary, with very finely drawn as well as purely empirical distinctions.

COMPARISON OF TYPES.

The discrimination between lignites and subbituminous coals presented in Table 1, which agrees with Campbell's classification (see p. 10), has the great merits of simplicity and naturalness of grouping, readiness of application, and practical freedom from technical criteria. It is the only kind of classification that is adapted to common usage. Yet the difficulties due to the transitions from group to group are not less real and perplexing. Neither is it strange that, being based on physical characters and weathering criteria, it does not conform wholly to the conditions indicated by the analyses.

The fixed carbon column of Plate III shows conspicuously a somewhat indiscriminate mingling of lignites (L), subbituminous coals (S), and low-grade bituminous coals. In the ratio columns the intermingling of lignites and subbituminous and bituminous coals appears to be limited to border zones, the more important transgressions being those caused by weathering of the coals.[b] So far as present analyses are competent to serve as a basis for calculations it seems that in most coals the H:O ratio may provisionally be regarded as ranging up to 22 in the peats; from 22 to 29 in the lignites (brown coals);

[a] Additional field observations are needed on this point. [b] No. 2b (F. C. 50.53) is weathered.

from 28 to 38 in subbituminous coals; and from 31 upward in the younger low-grade bituminous coals, or from 40 upward in the Paleozoic coals. The ratios, as may be noted in Plate III, do not all fall within these limits; but it is believed that additional data (which are much needed) will show that they fall generally within the limits here provisionally outlined. The lowest ratio for a Paleozoic coal in the table is 38.3 for a Zeigler analysis (F. C. 62.74). Mr. Campbell's classification is thus seen greatly to lower the under limit of the bituminous category, so as to include therein a large number of coals which are much less advanced in the coal-forming process than the lowest grade of the American Paleozoic coals.

It is well known that the coals of certain districts exhibit characteristics peculiar to the district or perhaps to their kind. For example, the xyloid lignites of North Dakota are in general marked by low H:O ratios; the Kootenai coals of the Great Falls field have comparatively low hydrogen and carbon in their volatile, and consequently low H:O ratios, though, on account of the great amount of charcoal, their fixed carbon is as high as that of many of the fine coking coals of the Appalachian trough;[a] but it is also true that the differences due to geologic period are, in coals of the same initial classes of ingredient matter and conditions of biochemical action, obliterated, so far as may be seen in the ultimate analysis, by dynamic influences expressed in metamorphism and progressive devolatilization

OBLITERATION OF DISTINCTIONS AS A RESULT OF REGIONAL METAMORPHISM.

Comparative examination of the coals assembled in the accompanying tables shows most convincingly the efficient work of the dynamochemical processes in wiping out all the important distinctions due to differences in the age of the fuel. Under this action the coals of all epochs undergo essentially the same experience of progressive devolatilization, deoxygenation, and concentration, though not without great waste, of carbon and hydrogen. The closeness of the agreement between the corresponding advanced stages of the older and the younger coals is shown by their industrial adaptation as well as by the ultimate chemical analysis. The high-grade coking coal and semianthracite of the western Upper Cretaceous and Tertiary formations are as truly coking and semianthracite as though they had grown in the vast umbrageous swamps of the Paleozoic. The brown coals of North Dakota are progressively transformed to semibituminous and to bituminous as they extend farther within the regions of the increased geodynamic action which effected the further upthrust of the Rocky Mountains. The Cretaceous coals of

[a] Compare No. 73b (F. C. 64.39); No. 44b (F. C. 65.74); and No. 25a (F. C. 65.91).

the Crested Butte, Colo., region are transformed to semibituminous coking coals and to anthracites under dynamic influences, the chief of which is, I believe, horizontal thrust pressure under loading. Only very rarely, and in very restricted localities, is the metamorphism due to plutonic intrusives or overflows.

To a limited but convincing extent these changes may be followed in the same bed as well as in the same geologic formation and region. It appears only to be necessary that the coals be of the same kind at the beginning in each case. If xyloid lignites they become xyloid bituminous coals; if cannel brown coals they become bituminous cannels, etc. There appears to be no important difference in mode of formation or composition between the Upper Cretaceous cannel coals near Cedar Valley in Utah and those of the upper Pottsville in eastern Kentucky. The dull, dense, "amorphous" bands, sometimes approaching a bastard cannel, which may not infrequently be observed in the Paleozoic coals of the Appalachian trough, are both in their nature and in the conditions of their formation exactly like those similarly found in the Cretaceous and Tertiary coals and in the Pennsylvania anthracites. The differences, principally relating to the degree of elimination of the oxygen content, mark the progress of the dynamochemical work in the process of coal formation.

OXYGENATION AND WEATHERING OF COALS.

CHANGES IN LOW-GRADE COALS.

Both in connection with the discussion of the causes of variance from the C:(O+ash) ratio and efficiency curve, and in the review of the comparative standing of the H:O ratios in Plate III, it has been noted that in general the lower classes of coals take oxygen on exposure to the atmosphere. This, together with some immediate loss of compressed volatile matter, appears to mark the first phase of weathering. Later, and on prolonged exposure, there seems to be considerable loss of carbon and hydrogen also, especially in the humic (ordinary) coals.

EFFICIENCY LOSSES IN WEATHERING.

The consideration of this subject engages us only in so far as it obviously affects the efficiency of the ratio curve. The analytical data now available in the reports of the coal-testing work are unfortunately deficient as to such samples and localities as alone will put in the hands of geologists and engineers the data necessary for knowing the total efficiency losses endured by some of our thinly covered or long mined, not to mention weathered, coals. An inquiry to show the kinds, degrees, and rapidity of loss under varying conditions would require a large number of ultimate analyses; but I am

confident that the results of a series of such observations would in many cases prove surprising as well as important.

The amount of oxygen that is assimilated and the rapidity with which it is taken up by certain subbituminous coals and lignites seem to indicate very unstable chemical conditions in the combustible matter of these coals as they lie deeply buried in the strata. It will later be seen that in some coals the amount of this absorbed oxygen exceeds the capacity of the hydrogen to form water.

LOSSES SHOWN BY ANALYSES AND RATIO-EFFICIENCY CURVE.

Mention has been made of the almost invariable calorific deficiency, as indicated by the curve, of those coals that have been weathered, taken from shaly or thinly covered mines, or country banks, or deep but abandoned mines. Most of these coals are from geologic formations or regions in which the coals are exceedingly low in sulphur, so that many of them should show excess curve errors if wholly unaffected; and this seems to be borne out by some of the better samples from the same districts. The few comparisons given below are offered rather as suggestions and as bases for rough estimates than as careful calculations based on representative, not to say ample, material.

Following are the analyses of two coals from the Lewis (Cretaceous) shale, 22 and 24 miles northwest of Fort Steele, Wyo. The coal is subbituminous. The first, No. 53a of Table 1, is from an entry near the foot of the shaft; the second was taken near the surface of the ground.

Comparison of two coals to show effect of weathering.

No.	S.	H.	C.	O.	Ash.	Moisture.	F. C.	H:O.	Av. H.	Calories.	Curve error.
53a	0.85	5.16	63.57	22.05	3.80	8.70	55.36	24.2	2.02	6,310	+ 30
Wyo. 3919 [a]	.31	4.90	59.86	29.39	4.12	9.34	55.57	18.3	1.23	5,636	−219

[a] Bull. U. S. Geol. Survey No. 316, 1907, p. 256.

The second of these analyses does not differ widely from the first if the first be recalculated after adding 10 per cent of oxygen. The difference in calories between the two analyses is 674. If a lump allowance of 50 calories is made for difference in ash, etc., in the second, we shall have left 624 calories as a rough estimate for the loss in weathering. In this case the loss would be about 62 calories for each 1 per cent of added oxygen. This is not far from the actual anticalorific value of oxygen in a coal having the same C:(O + ash) ratio as 53a. The effect of the added O is seen both in the reduced H:O ratio of the weathered specimen and in the VC:C ratio, which in the weathered is 19.48 as compared with 23.80 in the shaft coal. The fact that adding 10 per cent of oxygen to No. 53a creates a

small deficiency in the hydrogen, the carbon, and the H:O ratio, as well as in the available hydrogen, indicates either some loss of carbon and hydrogen in the deteriorated sample or that the absorbed oxygen is a little under 10 per cent, possibly as low as 7 per cent.

It will be borne in mind that the ratio-efficiency curve errors, which show large deficiencies in these deteriorated coals, may represent but portions of the real calorific losses; for the added oxygen has naturally had the effect of lowering the C: (O + ash) ratios, thus placing them lower in the curve. It is interesting to note, however, that the calorimetrically ascertained efficiencies of these weathered coals generally exceed those calculated by Du Long's formula.

LOSSES SHOWN BY H:O AND VC:C RATIOS.

Evidence of the effects of exposure or weathering is often obvious in the ratios as well as in the calorific deficiencies. This is represented graphically in Plate III. Usually the drop is more conspicuous in the VC: C ratios as here tabulated. Examples of coals from prospects whose ratios are to be interpreted as indicating deterioration are No. 62a (F. C. 61.62) and No. 72a (F. C. 60.89), both being bituminous coals. The subbituminous coal at Fall River, Wyo. No. 9a (F. C. 41.22), is placed among the brown coals below the other subbituminous coals in Plate III, as the result, I believe, of exposure.

A striking illustration of profound deficiencies in both ratios is seen in No. 2b, a subbituminous coal from the Labarge Range, Wyo. (F. C. 50.63), in which the H:O ratio is but 11.1, while the VC:C ratio is only 17.47. More remarkable still, there is a deficiency of 0.37 in the hydrogen necessary to form water in union with the oxygen of the coal. It therefore seems probable that part of the oxygen in this coal exists as CO, CO_2, or atmospheric oxygen. The table contains three other analyses (Nos. 55a, 44a, and 39a) from the same formation and district. The four analyses are repeated below.

Comparison of coals from same district, to show effects of weathering.

No.	S.	H.	C.	O.	Ash.	$\frac{C}{O+ash}$
55a	0.84	5.68	63.81	25.75	2.84	2.23
44a	2.10	5.74	61.76	25.96	3.41	2.10
39a	1.14	5.39	62.05	24.56	5.77	2.04
2b	.61	4.45	48.65	38.57	6.87	1.07

No.	Moisture.	F. C. in pure coal.	VC:C.	H:O.[a]	Av. H.	Calories.	Curve error.
55a	10.22	53.81	27.94	28.6	2.46	6,558	− 43
44a	10.78	52.06	28.85	29.0	2.50	6,057	−140
39a	9.02	56.51	23.37	27.4	2.32	6,039	− 90
2b	13.83	50.63	17.47	11.1	−.37	4,468	−150

[a] The H:O ratio is calculated on the moisture-free basis.

Nos. 55a and 39a are from drifts, and, although probably somewhat affected by influences from the surface, are relatively fresh. No. 44a, as might be suspected from its marked deficiency error, is from a prospect. It is presumably either deeper or newer than No. 2b, which is also from a prospect, since it shows less change from the composition of the deeper coals.

Since No. 39a, the third coal of the series, appears to agree in its main criteria with No. 2b, and since it may be, perhaps, safely regarded as not seriously weathered, it will be taken for comparison with the latter. A glance at the two analyses shows that the important differences between these coals concern the oxygen, the available hydrogen, and the calorific values. Examination of these differences makes it evident that if a little over 20 per cent of oxygen be added to that in No. 39a and the analysis of the latter be then recalculated to 100 per cent, the resultant percentages will fall reasonably close to the corresponding elements in No. 2b without further compensation. It therefore seems probable that the prospect coal in a less weathered state was essentially like that of the drift coal, No. 39a. The increase in oxygen was, perhaps, nearer 25 per cent. The accession of that amount of oxygen closely corresponds to the difference in the calorific values of the two coals, which amounts to 1,571 calories—that is, nearly 65 calories to each 1 per cent of added oxygen. This agrees closely with the ascertained anticalorific value of oxygen in a coal having a C:(O+ash) ratio near 2.00. Compensation for the difference in moisture, etc., in the coals seems to justify the conclusion that over 20 per cent of added oxygen has entered into combination with the fuel elements of the weathered coal.

It will also be observed that the assimilation of 20 per cent of oxygen in a coal like No. 39a will accomplish a little more than the extinction of its available hydrogen, causing a deficit of 0.18 in the amount necessary to form water. On the other hand, the elimination of 20 per cent of the oxygen in No. 2b, the weathered coal, will make available 2.13 per cent of hydrogen, which, if the analyses be recalculated to 100 per cent, will approach still closer to that of the other analyses.

Thus, in short, the evidence drawn from (*a*) the comparison of the analyses of the more with the less weathered fuel, (*b*) the probable loss in calorific value, and (*c*) the amount of the reduction of available hydrogen agrees in indicating a probable assimilation of 20 per cent or more of oxygen in the course of weathering. All things considered, it is perhaps safe to estimate the falling off in the efficiency of this subbituminous fuel at nearly one-fourth of its original heating power in the calorimeter.

The sample just discussed on account of its availability among the analyses studied in the preceding pages is not to be regarded as extraordinary or even unusual among weathered coals of its class. More strongly marked hydrogen deficiencies and more conspicuous degradations are to be found among the field samples.[a] Analyses of surface samples of coals of these grades are of little value in determining the characteristics of the coal, except in so far as they indicate the approximate amounts of sulphur and ash. Many of the analyses of coals from deep prospects and country banks are not to be taken as showing the real merits of the fuel.

It appears that in the lignites (brown coals) the deterioration is still greater; and it follows, almost as a certainty, that in some of the peats, particularly among the xyloid or more fibrous types, the loss of calorific value during the periods of drying, manufacture, and storage—that is, between the moment of exhumation from the pit bottom and the time of deposition in the crucible or on the grate—may be very serious. It may not be extreme to suggest that this loss possibly amounts in certain cases to as much as that incurred through weathering in some of the subbituminous coals.

UNDERGROUND WEATHERING.

The analyses bear evidence, according to my tentative interpretation, that the phenomena of weathering are not confined to outcrops or shallow prospects. There are a number of coals in which I suspect oxygenation to have taken place to some extent in shallow mines or country banks and drifts which have not penetrated too far from the surface. An example of these is No. 2a from near Miles, Mont.[b]

A sample showing what I am inclined to interpret as oxygenation as the result of exposure to air for a long period in a large mine of good depth comes from the No. 6 mine at Rock Springs, Wyo. This mine is said to have been abandoned about ten years ago. The coal is subbituminous and of high quality, as will be observed from the analysis.[c]

Below is given, from Table 1, the analysis (air-dried basis) of No. 144, the coal from No. 10 mine at Rock Springs, Wyo., as in car sample at the fuel-testing plant of the United States Geological Survey; and following it the analysis from the abandoned No. 6 mine, recalculated to the same percentage of moisture as No. 144.

---

[a] See analyses published in Bull. U. S. Geol. Survey No. 316. Examples are Wyoming 3695 and 3697, p. 237.

[b] See also No. 4a from near Glendive, Mont.; Nos. 175a, 166a, 146c, 72a, and 62a.

[c] Analysis included by courtesy of Mr. M. R. Campbell.

Comparison of coals showing effect of long exposure to air in abandoned mine.

No.	N.	S.	H.	C.	O.	Ash.	Moisture.	Calories.	H:O.	Av. H.	VC:C.	F.C.
144.....	1.52	0.86	5.37	70.30	18.32	3.63	6.00	6,955	36.2	3.08	26.49	57.19
Wyo. 6042.	1.46	.46	5.01	66.32	22.03	4.72	6.00	6,340	26.1	2.23	15.41	62.88

If to sample 144, from the active mine, we add 5 per cent of oxygen and recalculate to a basis of 100 per cent, compensating the calorific value, we have:

Recalculation of analysis of sample 144.

Nitrogen.....	1.45	Ash.....	3.46
Sulphur.....	.82	Moisture.....	5.71
Hydrogen.....	5.11	Calories.....	6,624
Carbon.....	66.95	H:O ratio.....	26.3
Oxygen.....	22.21	Available hydrogen.....	2.33

This analysis, as will at once be recognized, approaches substantially that of the sample from the abandoned mine. In nitrogen, carbon, and hydrogen the agreement is satisfactorily close, as is also the amount of available hydrogen, which becomes 2.33 compared with 2.23. In fact, the agreement between the recalculated No. 144 and the abandoned-mine analysis is sufficiently close to justify the conclusion that, together with the other presumable changes, 5 per cent or more of oxygen had probably been assimilated in the coal deep in the old mine on account of exposure to air since its abandonment. The difference in the calorific value is disproportionate to that which might reasonably be expected from the mere addition of 5 per cent of oxygen, and offers ground for the suspicion that there has been a small loss in carbon and hydrogen. The calorific difference, roughly compensated for difference in ash and sulphur, amounts to about 535 calories, or about 105 to each 1 per cent of assumed oxygen increase. This, as shown on page 40, is probably as much as 10 calories in excess for added oxygen.

It is probable that in the subbituminous coals, and more especially in the lignites, oxygenation begins immediately after the coal is blasted from the face in the mine. Zincken[a] quotes Bischoff to the effect that the brown coal of Pützchen absorbed 11 per cent of oxygen from the atmosphere in eight days. More recently Stremme and Späte[b] have shown some absorption even by sapropelic coals standing for various periods in a museum. It should be noted, however, that the sapropelic or alga coals are very much less susceptible to oxidation on exposure than are the more bituminous coals, which are humic.

[a] Physiographie der Braunkohlen, 1867, p. 8. See also Muck, Chemie der Steinkohlen, 1891, p. 109.

[b] Zeitschr. angew. Chemie, vol. 20, pt. 43, 1907, p. 1841; also Zeitschr. Deutsch. geol. Gesell., Monatsber., Nos. 7 and 8, 1907.

It is not impossible that some of our peats will be found to assimilate still greater quantities of oxygen on exposure. This question, as well as that of the immediate loss of volatile in freshly mined lignites or subbituminous coals, is one deserving careful examination. The results of the very interesting, as well as important, investigations recently published by Parr and Hamilton,[a] show that deterioration is strongly marked and rapid, even within short periods, in coals so old and well established in coal formation as those of the Illinois region, where an efficiency of 2 to 10 per cent may be lost on exposure for seven months. A still greater susceptibility to change is, I believe, to be expected in the higher-grade bituminous coals of some portions of the western Mesozoic and Tertiary coal fields, in which the dynamic influence is still in vigorous action, locally at least, as shown by rapid loss of volatile, and in which, on account of lack of time in which the volatile might effect its escape (with concomitant readjustment of compounds to comparative equilibrium in conformity to the new conditions), it may be assumed that the hydrocarbon compounds are in a state of highly unstable equilibrium. The susceptibility to deterioration is doubtless far greater in many of the subbituminous coals and lignites.

LOSSES BY WEATHERING IN SHIPMENT.

A comparison of the calorific values of the car samples with the ratio curve on the one hand and with a few mine samples collected by the field geologists on the other, seems to me to warrant the apprehension that in some samples at least a considerable deterioration has occurred before the actual analysis of the fuel. My personal opinion, based upon quite insufficient data, is that the car samples of most of these lignites and of many of the subbituminous coals are calorifically deficient to an extent of 50 calories as compared to the probable efficiency of freshly mined and tightly sealed mine samples, provided the latter are analyzed immediately upon opening. It may not be overhazardous to estimate that some of the published calorific values are as much as 200 calories less than the efficiency of the coal in the ground. The coal No. 51a, from Batan Island, P. I., may be mentioned as a good example of probable loss between the coal bed and the crucible. Analyses Nos. 3, 13, 19, 22, 32, 56, 83, and 144 also appear to justify suspicion.

The amount of loss depends not only upon the kind of coal, but also on the conditions of loading, the kind of car, the size of the fragments, the weather, the period of transit (which for many coals is over three weeks), and the mode of sampling from the car. The present method of air drying the coal in an oven under a current of

[a] Econ. Geology, vol. 2, 1907, p. 693.

warm air in the laboratory may also be mentioned as seeming most favorable to the oxygenation of the fuel and its consequent rapid calorific deterioration.

For commercial purposes the current methods of sampling and analysis appear to be very satisfactory and even indispensable, since they show the composition of the coal as it is ordinarily received at its industrial destination. Yet it is possible that a thorough investigation of the impairment of the lowest-grade fuels on exposure will show a calorific loss in some coals that is so great within a short time as perhaps to call for new methods of handling.

The above observations, it must be remarked, are disconnected and fragmentary, and crude both as to methods and results. Their purpose is mainly to stimulate observation. I anticipate, however, that properly made tests and careful calculations, based on adequate data, will show the importance of the subject to have been on the whole understated.

SUMMARY.

1. Coals with high oxygen and low ash will, in general, have very nearly the same efficiency in the calorimeter as other coals with alternated percentages, low oxygen and high ash, if the total carbon is the same. This applies to both air-dried and moisture-free coals.

2. Oxygen and ash are of very nearly equal anticalorific or negative value, ash being probably slightly more injurious in most coals; the negative value of the oxygen of moisture is not far different from that of the oxygen combined in the coal.

3. The calorific value of coals in general is essentially indicated by the balance between the total carbon, on the one hand, and the sum of the two great impurities, oxygen and ash, on the other, the hydrogen, nitrogen, and sulphur being usually negligible as "constants."

4. Except in the presence of unusual variations of hydrogen or sulphur, the efficiencies of the coals, if ash be constant, rank nearly in the order of the ratios C:O, which in each kind of coal marks the progress of coal formation under dynamochemical influences.

5. Oxygen and ash being of approximately equal anticalorific potency the efficiencies of the coals conform fairly closely to the order of the ratios C:(O + ash), so that among coals of all kinds those having the same ratios are found to have not far from the same efficiency. The causes of the greater departures are mentioned in the next paragraph.

6. A miscellaneous series of coals of all kinds, ages, and regions, when platted according to the C:(O + ash) ratios and calorific values as components, describe a curve to which they conform very closely, the average variance being less than 1 per cent of the calorific value. The greatest variances are among (*a*) weathered coals, (*b*)

those having 79 per cent or more of fixed carbon in pure coal—that is, those undergoing anthracitization—and (*c*) the boghead-cannel group, in which the hydrogen is excessively high, so that the efficiencies describe a higher curve characteristic of the group.

7. The departures from the ratio-efficiency curve on account of unusually high or low available hydrogen are generally not large. High sulphur is usually attended and compensated by high hydrogen, the converse being true to a less extent. Unusually high sulphur acts, on the whole, as a diluent, while very low sulphur leaves the relative field to the heat-determining elements. Consequently the variances from the curve on account of the neglected constants—hydrogen, sulphur, and nitrogen—are rarely over 2 per cent unless in the exceptions noted in paragraph 6.

8. Types of coals are initially determined by the nature of the ingredient matter, the conditions of deposition, and the extent of operation of the first or biochemical process in coal making; but progressive devolatilization, lithification, cleavage, and other accompanying alterations result from the second or dynamochemical stage of coal formation, which in each kind removes the essential distinctions of age or region, even tending ultimately to obliterate the differences in kind. Consequently any classification of coals based on the present form of ultimate analyses must be arbitrarily defined. There is intergradation in all parts of the process of coal conversion and coal alteration, as well as in the ingredient matter and conditions of deposition.

9. The weathering of the lower grades of coal, especially the lignites, bituminous coals, and peats, is marked by the accession of oxygen, which is taken into combination. This increase of the oxygen contents, which seems to indicate lack of equilibrium in the hydrocarbon compounds of the normal coal, readily permits a calorific deficiency, which, on account of the high anticalorific value of oxygen, is often serious. It is possible that in many cases considerable increase of oxygen and consequent loss of efficiency are suffered by the lower-class fuels between removal from the bed and deposit in the grate or the chemical crucible.

10. The adaptability of a coal to coking by the ordinary process appears to be indicated with a fair degree of certainty by the ratio of the hydrogen to the oxygen, moisture-free basis. Practically all coals with H:O ratios of 59 (per cent) or over seem to possess the quality of fusion and swelling necessary to good coking. Most coals with ratios down to 55 will make coke of some kind, while a few coals with ratios as low as 50 coke in the beehive oven, though very rarely producing a good article. The coking property seems to depend, not so much on the amount of available hydrogen, which is a very imperfect index of the proportion of the elements in the

volatile, but on the relative amount of the hydrogen as compared to that of the oxygen. In those coals undergoing change to anthracite, the hydrogen-oxygen ratio may fail as a guide; the failures appear, however, to be readily distinguished by the marked calorific deficiencies shown by the C:(O+ash) ratio and efficiency curve. The data examined, though insufficient to serve as a basis for a conclusion, seem to point toward the need of a relatively high carbon element in the remaining volatile combustible of coals with 79 per cent or more of fixed carbon (pure coal), in order to secure either the best coking results or the calorific efficiency indicated by the C: (O+ash) ratio-efficiency curve.

PARTIAL BIBLIOGRAPHY.

SURVEY PUBLICATIONS ON COAL.

A bibliography of United States Geological Survey publications containing references to coal is given in Bulletin 341, Contributions to Economic Geology, 1907, part 2, pages 419–436. The following publications treating of the work of the Survey fuel-testing plants contain many analyses of coals. The Survey's supply of those designated by an asterisk is exhausted, but they can be purchased from the Superintendent of Documents, Government Printing Office, at the prices named. Copies of the others can be obtained free by applying to the Director of the Geological Survey.

BULLETIN 261.* Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

PROFESSIONAL PAPER 48.* Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1492 pp., 13 pls. $1.50.

BULLETIN 290.* Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

BULLETIN 323.* Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp. 10 cents.

BULLETIN 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907; J. A. Holmes in charge. 299 pp.

BULLETIN 336.* Washing and coking tests of coal and cupola tests of coke conducted by the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to June 30, 1907, by Richard Moldenke, A. W. Belden, and G. R. Delamater, with introduction by J. A. Holmes. 1908. 76 pp. 10 cents.

BULLETIN 362.* Mine sampling and chemical analyses of coals tested at the United States fuel-testing plant, Norfolk, Va., in 1907, by J. S. Burrows. 1908. 23 pp. 5 cents.

BULLETIN 363. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests and some foreign specifications for briquetted fuel, by W. F. M. Goss. 1908. 57 pp., 4 pls.

BULLETIN 368. Washing and coking tests of coal at Denver, Colo., by A. W. Belden, G. R. Delamater, and J. W. Groves. 1909. 54 pp., 2 pls.

MISCELLANEOUS RECENT PUBLICATIONS.

The following books and papers treat of the composition of coals:

1905.

DONATH, ED., Betrachtungen über das Backen und über die Bildung des Steinkohle, Oesterr. Zeitschr. Berg. und Hüttenwesen, January 11, 18, 25.

FULTON, J., Coke, A treatise on the manufacture of coke and other prepared fuels. Scranton.

POTONIE, H., Die Entstehung der Steinkohle und verwandter Bildung einschliesslich des Petroleums. Berlin. 45 pp.

1906.

BEMENT, A., The sampling of coal. Jour. Am. Chem. Soc., vol. 28, pp. 632–639.

CAMPBELL, M. R., The classification of coals. Trans. Am. Inst. Min. Eng., vol. 36, pp. 324–340.

FRAZER, PERSIFOR, The classification of coals. Trans. Am. Inst. Min. Eng., vol. 36, pp. 825–833.

PARR, S. W., Composition and character of Illinois coals. Bull. Illinois State Geol. Survey No. 3.

——— The classification of coals. Jour. Am. Chem. Soc., vol. 28, pp. 1425–1432. Also Mines and Minerals, December.

1907.

DIRKE, H, B., Illinois coal tests. Eng. Record, February 25.

GREENWELL, A., and ELSDEN, J. V., Analyses of British coals and coke and the characteristics of the chief coal seams worked in the British Isles. London. 405 pp.

GROUT, F. F., The composition of coal. Econ. Geology, April–May, pp. 225–241.

HEADDEN, W. R., A study of some Colorado coals. Proc. Colorado Sci. Soc., vol. 8, pp. 281–300.

KEIGHLEY, F. C., Why do some coals coke? Mines and Minerals, October.

MACCALLUM, H., The classification of coal. Canadian Min. Jour., May 1.

MUCK, F., Die chemie der Steinkohle. Leipzig. 66 pp.

PARR, S. W., Heat production and the constituents of coal. Eng. and Min. Jour., June 29.

PARR, S. W., and HAMILTON, N. D., The weathering of coal. Econ. Geology, October–November, pp. 692–703.

——— ——— The weathering of coal. Bull. No. 17, Univ. Illinois Eng. Exper. Sta., 37 pp.

POTONIE, H., Historiches zur Frage nach der Genesis der Steinkohle. Naturw. Wochenschr., vol. 6, pp. 113–117.

WOODMAN, J. E., Coal sampling. Canadian Min. Jour., May.

1908.

CAMPBELL, M. R., A practical classification of low-grade coals. Econ. Geology, March–April, pp. 134–142.

DOWLING, D. B., Classification of coals by the split volatile ratio. Canadian Min. Jour., April 15, pp. 143–146.

PISHEL, M. A., A practical test for coking coal. Econ. Geology, June–July, pp. 265–270.

PORTER, F. C., and OVITZ, F. K., The nature of the volatile matter in coal as evolved under different conditions. Jour. Am. Chem. Soc., vol. 30, pp. 1486–1507.

WHITE, DAVID, Some problems in the formation of coal. Econ. Geology, June–July, pp. 292–318.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 383

NOTES
ON
EXPLOSIVE MINE GASES AND DUSTS

WITH SPECIAL REFERENCE TO

EXPLOSIONS IN THE MONONGAH, DARR, AND NAOMI COAL MINES

BY

ROLLIN THOMAS CHAMBERLIN

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

CONTENTS.

	Page.
Introduction	5
Character of the report	5
Explosions studied	6
Gases found in the mines	7
Methods of collecting	7
Analyses	8
Methane	9
After damp	11
Deficiency of oxygen	15
Possible conditions of gas in coal	16
Liberation of gas by crushing coal	17
Plan of experiments	17
Method of crushing	18
Detailed results	18
Gases from coal bottled in a vacuum	24
Vacuum bottles	24
Volume of gas	24
Character of gas	25
Comparison with mine gases	31
Rate of escape	33
Practical significance of rate	36
Effect of barometric changes	37
Gases obtained by heating coal	39
Studies on coal dust	42
Evidence that dust took part in explosions	42
Character of dust deposits	44
Dust samples	45
Explanations of dust effects	46
Cause and manner of coking	48
Loss of volatile matter	49
Comparison of other dust samples	51
Restraining factors—shale and dampness	52
Practical considerations as to danger of explosions	54
Influence of seasonal change	54
Effect of shale dust on explosions	55
Comparative inflammability of old and fresh coal dusts	56
Supposed danger in old dust	56
Tests on differently exposed samples	57
Significance of tests	58
Absorption of oxygen by coal	60
Decrease in combustible gases	62
Conclusion—fresh dust more dangerous	63

ILLUSTRATION.

Page.
FIGURE 1. Diagram showing rates of escape of methane from coal..... 34

NOTES ON EXPLOSIVE MINE GASES AND DUSTS, WITH SPECIAL REFERENCE TO EXPLOSIONS IN THE MONONGAH, DARR, AND NAOMI COAL MINES.

By Rollin Thomas Chamberlin.

INTRODUCTION.

CHARACTER OF THE REPORT.

The studies herein reported were begun as a part of researches undertaken by the United States Geological Survey looking to the more efficient utilization of the coal in the United States through the reduction of waste in its extraction, and were continued as part of further researches having regard to the conservation of the fuel resources of this country and to the lessening of injuries and fatalities in coal mining.

Among other phases of the general problem to be studied were the origin of the gas which escapes into coal mines, its modes of occurrence in the coal and rock strata, and the conditions governing its outflow into the mines. The subject of relative danger from destructive explosions due to gas and coal dust in different mines belonging to different coal fields was to be one of the principal lines of investigation.

But this work was barely under way when the series of unusually disastrous explosions in the Naomi, Monongah, and Darr mines of Pennsylvania and West Virginia, in December, 1907, afforded an exceptional occasion to observe the behavior of explosions on a large scale. Because of the opportunities for study afforded by these terrific explosions, the inquiry originally planned was diverted to the more specific investigation of the conditions in these mines, and the examinations have been directed toward finding those qualities of gas and dust which were concerned in these explosions. The following discussion, therefore, consists essentially of a report on that subject; but it is far from being exhaustive, and is to be regarded as a preliminary outline of investigations which are still in progress.

EXPLOSIONS STUDIED.

The first of the three mine explosions mentioned occurred in the Naomi mine of the United Coal Company, near Bellevernon, Pa., on Sunday, December 1, at 7.40 p. m. All the men who were within the mine at the time, fortunately only 34, were killed.

Less than a week later there occurred in mines Nos. 6 and 8 of the Fairmont Coal Company at Monongah, W. Va., the most disastrous mine explosion yet recorded in the annals of American mining. The mines were comparatively new and well laid out. Mine No. 8 had been in operation only about two years and was the pride of the Fairmont Coal Company. Mine No. 6 was first opened about four years earlier. In order to make it possible, in case of emergency, for either mine to be ventilated by the ventilating system of the other, the two sets of workings were connected underground. The F face heading of mine No. 6 led directly into No. 2 north heading of No. 8 mine. On Friday, December 6, at about 10.30 in the morning, an explosion of unusual violence swept completely through both mines, pursuing its course throughout the numerous ramifications and bursting out of the two pit mouths, located 1¼ miles apart, nearly simultaneously. The slope of mine No. 6 was only slightly damaged, but at the mouth of No. 8 the destruction was very great. The fan was wrecked, the engine house was demolished, and mine timbers were blown across Monongahela River. As nearly as can be determined, 361 men were killed in the two mines by the explosion.

While the inspection of the Monongah mines was still in progress, on Thursday morning, December 19, at about 11.20, a similar explosion wrecked the Darr mine of the Pittsburgh Coal Company at Jacobs Creek, Pa.; 238 men lost their lives in this explosion, which in number of casualties is second only to the Monongah disaster in the history of American mining. Of all the men in the mine at the time of the explosion, only one man, who happened to be within 100 feet of the surface on an old manway in a wet, unexploded portion of the mine, succeeded in escaping alive.

The underground investigation of these mines was made in cooperation with Clarence Hall and Walter O. Snelling, of the United States Geological Survey, and James W. Paul, now of the Survey but at that time chief of the department of mines for West Virginia, to all of whom the author is greatly indebted for valuable assistance, suggestions, and advice. Mr. Paul will report on the nature of these explosions, the precipitating causes, their destructiveness, and the general conditions in these mines following the disasters. The present report is confined essentially to the laboratory examination of some of the explosive materials collected from these mines directly after the explosions.

GASES FOUND IN THE MINES.

METHODS OF COLLECTING.

As soon as practicable after these explosions samples of the mine atmosphere were collected at the coal faces and from the return air ways in various parts of the mines. It was hoped that something as to the nature of the after damp might be determined, but as the exploration of the mines could be carried only where there had been a certain amount of ventilation, the samples of after damp were necessarily greatly diluted with air. With the aid of breathing helmets and compressed-air cylinders attempts were made to collect after damp in the tight places where there appeared to have been little ventilation, but the subsequent analyses have shown that the proportion of after damp remaining was small. Other samples were taken to determine the accumulation of fire damp in the workings.

The samples of air and gas from these mines were collected for analysis in glass tubes of 125 cubic centimeters capacity. These tubes were drawn out to a 5-millimeter bore at each end, over which was slipped a piece of red antimony rubber tubing 5 to 6 centimeters in length. Before entering the mine each tube was filled with water, and a tight-fitting plug of glass rod was inserted in the rubber tubing at each end. To take a sample of the mine air the glass plugs were removed from the ends of the tube, allowing the water to run out and be replaced by air, after which the ends of the tube were securely closed by the plugs and the rubber connections tightly wired with copper wire. Glass tubes thus sealed were found to hold gas samples for several weeks without apparent change from leakage or diffusion. However, as a thin film of water always remains upon the walls of the tube when the gas is collected in this manner, it is inevitable that a small amount of carbon dioxide be absorbed. Haldane[a] has called attention to the fact that when gas samples are collected in glass tubes whose walls are moist, a small amount of carbon dioxide is absorbed by the sodium silicate of the glass. If the water used be clear, the gas sample loses a small amount of carbon dioxide, but if the water used be dirty, the sample may gain carbon dioxide from the action of bacteria. The samples of gas collected in the Naomi, Monongah, and Darr mines are all subject to these criticisms. Clear water was used in every tube but one, No. 26, which had to be refilled from a pool of standing water in the mine. Whenever the sample could not be analyzed within a few days after it was collected, the rubber connections were completely coated with paraffin, thus preventing with certainty any passage of gas through the rubber.

The samples of gas obtained from these mines were for the most part selected either from points in the workings where there appeared

[a] Foster, Sir Clement, and Haldane, J. S., The investigation of mine air.

to be unusual quantities of fire damp, or where the presence of after damp was suspected. Other samples were collected from the return air currents to obtain information upon the general character of the air throughout certain sections of the mines. Except in one or two special cases, the samples were collected just below the roof, in order to obtain a proportion of methane somewhat near the maximum present in the air. This was thought desirable because the gas near the roof would be most likely to be ignited from an open light upon a miner's cap, and because the maximum percentage of marsh gas in an entry gives the best indication of the danger from gas.

ANALYSES.

The analyses of the samples of gas collected within these three mines are given in the table which follows. The first 18 analyses were made according to the technical method of gas analysis described by Hempel.[a] The remainder of the analyses, with the exception of Nos. 23 and 29, were carried on over mercury in the apparatus devised by Professor Bone, of the University of Leeds.[b]

Analyses of samples of gas taken in Monongah, Naomi, and Darr mines.

[Figures give percentage.]

No.	Place.	Date.	CO_2.	CO.	C_nH_{2n}.	CH_4.	O_2.	N_2.
1	Monongah, mine No. 8; room 13 on fifth right, off No. 2 north heading	*1907.* Dec. 12	0.16	.....	.....	1.59	20.48	77.77
2	Monongah, mine No. 8; room 19 on fifth right, off No. 2 north heading	Dec. 12	.41	0.05	.....	.85	19.44	79.25
3	Monongah, mine No. 8; return air way of fifth right, off No. 2 north heading, opposite room 15	Dec. 12	.63	.06	.....	.09	19.82	79.40
4	Monongah, mine No. 8; No. 1 south heading, 350 feet inby third right	Dec. 12	.05	.02	.....	.....	20.55	79.38
5	Monongah, mine No. 6; H manway, 30 feet from coal face	Dec. 13	.10	.....	.....	.65	20.61	78.64
6	Monongah, mine No. 6; face of H entry	Dec. 13	.17	.05	.....	1.23	20.24	78.31
7	Monongah, mine No. 6; face of No. 4 right heading, off F face entry	Dec. 13	.19	.02	.....	.48	20.48	78.83
8	Monongah, mine No. 6; room 27 on fourth right, off F face entry	Dec. 13	.40	.07	.....	8.37	18.40	72.76
9	Monongah, mine No. 6; main south return air way, 50 feet from bottom of shaft to fan	Dec. 16	.20	.....	.....	.22	20.40	79.18
10	Monongah, mine No. 6; main right return air way, 200 feet inby A face entry	Dec. 16	.18	.02	.....	.45	20.33	79.02
11	Monongah, mine No. 8; face of north return air way to the mains	Dec. 17	.88	.21	.....	1.35	19.43	78.13
12	Monongah, mine No. 8; face of left return air way of third north	Dec. 17	.54	.27	.....	9.44	16.88	72.87
c13	Monongah, mine No. 8; room 27 on second left, off No. 2 north heading	Dec. 20	.42	.05	.....	1.32	19.80	78.41
14	Naomi mine; face of right main	Dec. 14	.32	.....	.....	20.99	16.37	62.32
15	Naomi mine; face of entry 35	Dec. 14	1.15	.06	.....	21.59	15.11	62.09
16	Naomi mine; main return air current, center main, 1,800 feet from mouth of slope	Dec. 14	.26	.02	.....	.75	20.11	78.86
c17	Darr mine; left return air way just inside of first crosscut to left inby swamp entry	Dec. 21	1.07	.61	.....	2.51	17.50	78.31
18	Darr mine; from same point as No. 17	*1908.* Jan. 1	.49	.01	.....	1.50	19.67	78.33
19	Darr mine; return air current at first face entry 30	Jan. 1	.99	.25	.....	1.14	18.06	79.56
20	Darr mine; from first left butt, 30 feet from entry 30	Jan. 1	.72	.18	.....	1.55	18.64	78.91
21	Darr mine; main entry 5 feet inby third right crosscut, inby entry 30	Jan. 1	1.04	.08	0.02	4.99	17.59	76.28

[a] Hempel, W. M., Methods of gas analysis, 1902: technical method.
[b] Bone, W. A., Jour. Soc. Chem. Ind., vol. 27, 1908, pp. 10-12.
[c] Collected by Clarence Hall.

Analyses of samples of gas taken in Monongah, Naomi, and Darr mines—Continued.

No.	Place.	Date.	CO_2.	CO.	C_nH_{2n}.	CH_4.	O_2.	N_2.
22	Darr mine; main entry, 20 feet inby fourth right crosscut, inby entry 30	*1908.* Jan. 1	2.31	.28	0.31	6.01	14.09	77.00
23	Darr mine; return air from swamp entry south air way, first break through	Jan. 2	1.36	.02	.....	.58	19.51	78.53
24	Darr mine; No. 12 right butt, off swamp entry 75 feet from face	Jan. 2	.67	.10	.....	6.25	18.16	74.82
25	Darr mine; 20 feet from face of swamp entry	Jan. 2	1.45	.....	.09	50.67	6.13	41.66
26	Darr mine; No. 12 right butt, off entry 27, 80 feet from face	Jan. 2	1.36	.11	.....	4.24	16.41	77.88
27	Darr mine; mouth of drill hole in face of right air course of main entry	Jan. 3	1.37	.03	.....	32.00	12.19	54.41
28	Darr mine; face of No. 12 right butt, off entry 27	Jan. 4	.59	.12	.09	7.99	17.57	73.64
29	Darr mine; from entry 30, 125 feet inby No. 1 left butt	Jan. 5	.79	.....	.....	2.12	17.61	79.48

METHANE.

It will be seen from the table that the highest percentages of methane (CH_4) were usually found in the samples collected at the faces of some of the mains. Methane in such high percentages occurred only more or less locally, either at the high points in the roof where, owing to its extreme lightness, it had accumulated, or as a thin stratum of fire damp floating along beneath the roof of an entry for a short distance from the coal face. Generally the diffusion of the gas was found to have taken place slowly in tight places where the current of air was slight, so that at a few rods from the face the percentage of methane in the air, even at the roof, was much reduced, while at the floor there was still less methane.

But in some places the gas was found to have become far more evenly distributed throughout the entries. In several of the entries in the Darr mine (see analyses 21, 22, 24, and 26) fire damp was detected in such quantities by the Wolf lamp, at distances of 75 to 100 feet from the coal face, that it was not thought advisable to push on to the faces even with safety lamps. Later, with an electric flash light to illumine the way, the faces of two of these three entries were visited. Tube 28, filled with air on January 4, 1908, from the face of No. 12 right butt, off entry 27, contained 7.99 per cent of methane, while tube 26, filled on January 2 at a point 80 feet from the face of this same entry, contained 4.24 per cent of methane. The conditions were similar at the face of the main entry. Tube 21, filled with air from the roof of the main entry, 5 feet inby the third right crosscut, inby entry 30, contained 4.99 per cent of methane, while tube 22, filled a few minutes later at a point 20 feet inby the fourth right crosscut (about 60 feet from the face of the main), contained 6.01 per cent of methane. Two days later a sample of gas (No. 27) was taken from the mouth of a drill hole 5 inches in diameter in the face of the right air course of the main entry. In this methane amounted to 32 per cent.

These figures show that the percentage of methane in the air near the roof of the gassy entries diminished rapidly with increasing distance from the face. This was true even in entries where the diffusion has been fair, for the Wolf lamp at the point where tube 21 was filled indicated gas as low as 2 feet above the floor. The high percentages of methane were chiefly local. The main return air currents, and in general those parts of the entries distant from the coal face, contained methane only in very much smaller proportions. In these passageways the gases had become more thoroughly mixed by diffusion as well as diluted in the draft of air, and hence here it made less difference whether the sample for analysis was collected at the roof or near the floor. An example of this was shown in No. 1 left butt, off entry 30, in the Darr mine. Tube 20, filled at the roof of the entry 20 feet inby from entry 30, showed only 1.55 per cent of methane. At this point a Wolf lamp on a tie showed a ¼-inch gas cap, indicating from 1 to 1.5 per cent of methane. As only a very slight current of air was moving out of this entry, the thorough mixing of the gases was apparently due largely to steady diffusion rather than to the air draft. Tube 29, filled with gas-laden air from the roof of entry 28, Darr mine, about 125 feet inby No. 1 left butt, contained 2.12 per cent of marsh gas. On the floor just below nearly a ½-inch gas cap was got with a Wolf lamp. The air was moving slowly.

In the main return air ways the fire damp was more diluted. On December 21, two days after the explosion in the Darr mine, when the ventilation was bad, the air from the return air way just inside of the first crosscut to the left, inby from the swamp entry, contained 2.51 per cent of methane (analysis 17); but the air at this same point on January 1, when the ventilation was better, contained only 1.50 per cent of marsh gas (analysis 18). On January 2 the return air from the swamp entry showed only 0.58 per cent of methane (analysis 23). Two days later a Chesneau lamp registered 1.4 per cent of fire damp where tube 18 had been filled, and 0.4 per cent in the return air from the swamp entry, indicating that, while there had been a slight improvement in the character of the air within these two days, the figures for tubes 23 and 18 are probably not far from the normal conditions. Where the Chesneau lamp registered 1.4 per cent of fire damp on January 4, and the chemical analysis of gas collected January 2 gave 1.50 per cent, the Wolf lamp on each occasion showed a ¼-inch gas cap.

In the Naomi mine, where very high percentages of methane were found at some of the entry faces, the main return air current on the center main, 1,800 feet from the mouth of the slope, contained, on the afternoon of December 14, 1907, only 0.75 per cent of marsh gas (analysis 16).

At Monongah there appears to be much less gas in the mines, both locally near the coal face, and in the return air in particular. In mine No. 6 the air of the main south return air way, 50 feet from the bottom of the shaft leading to the fan (analysis 9), and another sample from the main right return air way, 200 feet inby A face entry (analysis 10), contained, on December 16, 1907, only 0.22 and 0.45 per cent of methane, respectively. In mine No. 8 a test of the air collected on December 12 from the return air way opposite room 15 on the fifth right, off second north heading, showed only 0.09 per cent of methane (analysis 3). However, instead of collecting the gas from near the roof, the tube in this case was filled at a point about midway between the floor and the roof.

AFTER DAMP.

In all the samples of mine air collected in the Monongah, Naomi, and Darr mines within a few days after the explosions, the percentage of carbon dioxide greatly exceeded that of carbon monoxide. But it is true that none of these samples was collected until a fair state of ventilation had been reestablished after the explosions, such that parties could remain in the mines for several hours. The best of the samples was No. 17, taken from the Darr mine by Clarence Hall on the afternoon of December 21, two days after the explosion. While obtaining this sample three of the party were so overcome as to be forced to leave the mine. An analysis of this air showed 1.07 per cent of carbon dioxide and 0.61 per cent of carbon monoxide. No other sample approached this one in respect to the prominence of carbon monoxide, but even in this one the after damp was much diluted with air.

It may be instructive to undertake a rough calculation to show approximately what proportion of after damp is really present. Assume that essentially all of the oxygen of the air in the exploded portion of the mine was consumed in the explosion, and that carbon monoxide was formed because of insufficient oxygen, either directly or from the reduction of carbon dioxide by the floating particles of incandescent coal dust. Before making a computation of the proportion of after damp, it is necessary to decide to which of these reactions the carbon monoxide is to be assigned, as it makes a difference in the total resulting amount of carbon monoxide whether the monoxide be formed directly from the partial combustion of the gas or through the reduction by the glowing particles of coal dust of a portion of the carbon dioxide produced in the explosion.

Beard,[a] quoting Thomas, states that the explosion of a mixture of methane and air at the most explosive point (methane 9.57 per cent, air 90.43 per cent) produces no carbon monoxide, but that as

[a] Beard, J. T., Mine gases and explosions, 1908, p. 130.

the percentage of methane is increased above the point named carbon monoxide is formed in ever-increasing proportion until, at what he gives as the explosive limit, 16.67 per cent of methane in air, the result of an explosion would be 87 per cent monoxide and 13 per cent dioxide; while near the limit of inflammability, 29 per cent methane, no carbon dioxide is formed. He writes the equation $2CH_4+O_2+4N_2=2CO+4H_2+4N_2$.

Agreeing with this in a measure is the statement of the French fire-damp commission that the explosion of a mixture of methane and air, containing 12 per cent of methane, gave rise to the following gases: Carbon dioxide, 4.8 per cent; carbon monoxide, 3.9 per cent; methane and other hydrocarbons, 2.5 per cent; hydrogen, 3.5 per cent; nitrogen, 82.2 per cent; total, 96.9 per cent.

At variance with this, Broockmann concludes from his own experiments with the products of combustion of methane and air that a pure fire-damp explosion gives no carbon monoxide.[a] A mixture of air and fire damp containing from 10.8 to 13.5 per cent of marsh gas he found to give two separate flames. Expecting to find some carbon monoxide formed as the result of the first flame, Broockmann removed the products of the first combustion, in an exploding mixture of methane and air, before the appearance of the second flame, but in no case found a trace of carbon monoxide. Instead, the heat of the first combustion converted the unconsumed methane into acetylene and hydrogen. These doubtless furnish the fuel for the second flame.

Heise and Herbst also state[b] that a pure gas explosion never produces carbon monoxide, and that an explosion of air containing more than 9½ per cent of methane produces, along with steam, only carbon dioxide. Differing somewhat with Broockmann, they state that the two elements, carbon and hydrogen, which are combined in CH_4 become separated only when sufficient oxygen is present for the complete oxidation of both elements. Otherwise the compound does not allow itself to be split up.[c]

For the computation in the case in hand (analysis 17) it will be assumed that the carbon monoxide has not been produced directly from a partial combustion of methane and other hydrocarbon gases, but has resulted from a reduction of the carbonic acid by the particles of incandescent coal dust, according to the reaction $CO_2+C=2CO$. The analysis of the return air showed 1.07 per cent of carbon dioxide. From this are to be deducted both the percentage of carbon dioxode in the air, 0.03 per cent, for the after damp has been much diluted since the explosion, and also the carbon dioxide exhaled from the coal during that time. A rough estimate of the latter can be made,

[a] Broockmann, Niederrheinisch-Westfälischen Steinkohlenbergbaues, vol. 6, p. 52.
[b] Heise and Herbst, Bergbaukunde, vol. 1, 1908, p. 448.
[c] Idem, p. 463.

as the analyses of the gas issuing from the coal in the form of feeders and blowers, as well as from coal bottled in a vacuum, show that the proportion of carbon dioxide to methane in the gas escaping from the fresh coal of these mines is 1 or 2 to 100. As the percentage of methane was found to be 2.51, the amount of carbon dioxide which the fresh coal has contributed to the air since the explosion may be taken to be 0.03 per cent. This is the proportion of carbon dioxide to methane in the gas from fresh coal. In the older workings of the mine the proportion of the dioxide is greater than this; but in the absence of data upon the ratio of these gases escaping from coal which has long been exposed to the air, no allowance is here made for the greater proportion of carbon dioxide in the old entries. This leaves 1.01 per cent of carbon dioxide to be assigned to the after damp produced by the explosion.

To produce 1.01 cubic centimeters of carbon dioxide and 0.61 cubic centimeter of carbon monoxide from an explosion of methane, in cooperation with coal dust whose heated particles cause the formation of the monoxide by abstracting oxygen from a portion of the dioxide, 2.63 cubic centimeters of oxygen would be consumed, providing that all the hydrogen of the methane was burned to water.

This computation does not take into account the fact that, in addition to methane, other hydrocarbons participated in the explosion. These necessarily consisted of relatively more carbon than CH_4. But, on the other hand, the coal-dust particles which caused the reduction of the dioxide to the monoxide, instead of being pure carbon, contained a certain proportion of hydrogen, a portion of which was probably oxidized to water. These two factors tend to offset each other. Because of their complexity they can not be further treated here.

On the supposition that no carbon dioxide was absorbed by the water in the mine, and that all the oxygen in the air was consumed in the explosion, the volume of the oxides of carbon in the sample collected should bear the same relation to the amount of CO_2+CO originally developed by the explosion as the corresponding volume of oxygen, 2.63, does to 20.5, the percentage of oxygen which is assumed to have been originally present in the mine. This figure is taken because the coal rapidly absorbs oxygen from the air. The average proportion of oxygen in the air of tight places in this mine was found by a calculation from the analyses to be only 20.08 (see p. 15); but 20.50 would seem a better figure for the average of the mine air as a whole. The ratio $\frac{2.63}{20.5}$ is equal to 0.128, or from 12 to 13 per cent of after damp in the sample collected.

However, this can at best be only a rough estimate, as several uncertain factors are involved. The mine air previous to the explo-

sion contained a small and unknown quantity of carbon dioxide. But on the other hand, some carbon dioxide has doubtless been absorbed by the water in the mine since the explosion. In a measure these factors tend to offset one another. It is also true that other hydrocarbons, in addition to methane, were consumed in the explosion, and these would unite with oxygen in different proportions. But methane in all probability contributed most.

While this sample of the air from the Darr mine after the explosion shows that carbon monoxide may reach a considerable percentage in after damp, the other samples of the mine air which, however, were collected after better ventilation had been established, showed the presence of much less carbon monoxide, even though the proportion of the dioxide in some samples amounted to 1 per cent. It seems probable that some and perhaps most of the difference was due to more thorough ventilation before the later samples were collected, for carbon monoxide, once removed, would not be resupplied except in very small quantities, but carbon dioxide might have been supplied from the coal, the lamps, etc., since the explosion.

However, the relative proportions of carbon dioxide and carbon monoxide in after damp must always be variable, depending on the ratio between the available oxygen and the available combustible matter, gas and dust, in the air. If the explosion were due largely to methane in the air, in quantities not exceeding 10 per cent, and with little dust as an accessory, little carbon monoxide would be formed. But, on the other hand, in a dust explosion where large quantities of coal dust are present, capable of distilling volatile hydrocarbons in volumes too great to be entirely consumed by the quantity of oxygen in the mine air, and where there is an abundance of hot coal dust stirred up in the air, carbon monoxide might, perhaps, be produced in greater quantities than the dioxide. A coal-dust explosion is more complex than one of fire damp. If the explosion of the dust proceeds by rapidly feeding the flame with combustible gases and hydrocarbon vapors derived from it through the influence of the heat, as is believed to be the case, there is, at first, sufficient oxygen at hand to insure the complete oxidation of the gases developed. Carbon dioxide and steam result. But under ordinary conditions, with plenty of dust, the distillation of volatile matter continues, liberating an excess of readily available combustible gas which, because of insufficient oxygen, is only partly consumed. In the absence of oxygen, a portion of the carbon dioxide already produced is reduced to carbon monoxide in variable proportions, depending on the amount of red-hot dust floating in the atmosphere and the length of time during which the dust remains sufficiently heated to allow the reducing reaction to proceed.

DEFICIENCY OF OXYGEN.

In order to ascertain the character of the mine air, irrespective of the after damp, a recalculation of the analyses was made. The analyses of gas from mine feeders and from coal bottled in a vacuum show that the proportion of carbon dioxide to methane in the gas escaping from the fresh coal of these mines is 1 or 2 to 100. Wherever methane is found in the mines it is safe to assume that a volume of carbon dioxide corresponding to 1 per cent of the methane has escaped from the coal simultaneously with the marsh gas. This figure, plus the 0.03 per cent of carbon dioxide in normal air, is subtracted from the percentage of carbon dioxide in the analysis. To be on the right side, it is assumed that all the rest of the carbon dioxide has been produced by the oxidation of CH_4, as the combustion of this compound consumes more oxygen per unit of carbon dioxide formed than any of the other compounds which could have participated in the explosion. The amount of oxygen which would have been required, on the basis of an explosion of methane, to yield the oxides of carbon found in the analysis, is then added to the percentage of oxygen shown by the analysis. The percentage of methane in the analysis, plus the carbon dioxide of normal air and that which, on the basis of the methane present, has been considered to have been derived from the coal since the explosion, is deducted from the total, and the remaining figures recalculated so as to add to 100.

This gives an estimate of the percentage of oxygen in the mine air irrespective of the after damp from the explosion and the feeder gas which has escaped into the workings from the coal since the explosion. Because of the assumptions, these estimates give a generous figure for the percentage of oxygen. An average of the three analyses of air from the Naomi mine made in this way was 20.86 per cent, eleven analyses from the Monongah mine gave 20.72 per cent oxygen, and thirteen analyses from the Darr mine gave an average of only 20.08 per cent oxygen. These figures indicate a deficiency of oxygen in the mine air which can not be attributed to the formation of free carbon dioxide or carbon monoxide, unless it be supposed that much of the carbon dioxide formed has been absorbed by water in the mine, which seems improbable in these dry mines. Instead, it would appear that the coal has absorbed oxygen from the air, thus reducing the percentage of that gas and increasing that of nitrogen.

The greatest deficiency in oxygen occurred in the sample of gas-laden air collected near the face of the swamp entry in the Darr mine (analysis 25). Corrected for carbon dioxide and methane, this sample showed the unusual proportions, oxygen 16.13 per cent and nitrogen 83.87 per cent. This sample was also characterized by the highest proportion of methane (50.67 per cent) obtained in these

mines. That the diffusion of the air and gases in this cleft in the roof had progressed slowly is shown by the accumulation of so much fire damp, and it was apparently because of the stagnancy of the air in this nook that the coal was able to abstract such a proportion of the oxygen. It must be noted that feeder gas often contains several per cent of nitrogen, so that with 50 per cent of methane (feeder gas) present in the air a part of the apparent excess of nitrogen and deficiency of oxygen may, perhaps, be explained by this nitrogen coming from the coal.

As many of the samples of air which have contributed to these averages, particularly those from the Darr mine, were collected from sheltered, poorly ventilated nooks in order to get data on the accumulation of fire damp, the low figure of 20.08 per cent for oxygen is not representative for the air of the mine as a whole. While the loss of oxygen is less conspicuous in the general mine air than in pockets in the roof and in tight places where there is little air stirring, its effect is felt throughout the mine, and furnishes an additional reason for ventilation which will afford a continuous supply of good air, as well as remove the dangerous fire damp and the noxious products of combustion.

POSSIBLE CONDITIONS OF GAS IN COAL.

The gas which escapes from coal may exist within the mass of the coal in three possible conditions. It may be mechanically held or imprisoned in minute pores, cavities, or cracks throughout the coal; it may be occluded or dissolved within the substance of the coal; or it may be the result of slowly operating chemical reactions, such as those which have produced the coal from the original vegetable matter and which, still operative, might, as a working hypothesis, be supposed to generate gas in proportion as it is given off. In the first two cases the gases are supposed to be already existent within the coal as gases; under the third hypothesis they are to be regarded as now produced for the first time by chemical decomposition of the solid coal substance. The ultimate source of the gases may be taken as the same under each hypothesis, for there can be little doubt that the bulk of the gas given off from coal has arisen from the slow decomposition of organic matter as a by-product in the process which has converted vegetable humus into coal. The first hypothesis favors the belief that the gas-generating process has been very slow and that such gas as comes off at the present time has long been stored in minute cavities or pores, from which it escapes when the coal is fractured, as in mining operations. The second hypothesis assumes, like the first, that the gas was developed long ago, but differs from it in assuming that the gas, as fast as it was developed from the coaly matter, was retained within the coal substance in solution, or occluded,

instead of being held mechanically in minute crevices and cracks. This hypothesis is suggested by the well-known property of various metals to occlude or dissolve within their mass certain gases, and by the familiar power of charcoal to condense on its surface or absorb many times its own volume of various gases. The term occlusion, which Graham gave to this imperfectly understood property of certain metals to absorb particular gases, has been very loosely used, especially in mining literature, where "occluded gas" usually means gas held according to either of the first two hypotheses, the radical difference between them having generally been overlooked. By some writers, indeed, the term is intended to carry the idea of the first hypothesis alone, the second, that of true occlusion, being left out of account.

The third idea is only a working hypothesis which is framed to recognize the possibility that the coal-forming, gas-generating process is still in progress, and that the escape of the gases is a sort of index of the present chemical activity within the coal.

LIBERATION OF GAS BY CRUSHING COAL.

PLAN OF EXPERIMENTS.

To throw light on this possible threefold state in which the gases are held in coal, and to determine the relative importance of the three hypotheses, a series of experiments was devised. In the first the coal was broken up and crushed to a coarse powder in an air-tight receptacle, from which any gas liberated during the process of crushing can be extracted by a vacuum pump. Only such gas as was already stored in the coal can be freed by crushing it, as the process is accomplished very quickly. How much gas might be expected to be freed from a state of true occlusion by crushing is less clear. The most thoroughly studied form of occlusion is that of hydrogen by palladium. Whether palladium charged with hydrogen will give off part of its gas at the ordinary temperature when placed in a vacuum depends entirely on the condition of the metal. If the palladium is in a very finely divided state, a considerable portion of the hydrogen is given off when the pressure is greatly reduced;[a] but the cast or forged metal gives off no hydrogen whatever when placed in a vacuum at ordinary temperatures.[b] The hydrogen begins to be evolved from the solid metal only at temperatures above 100° C. It is conceivable that reducing the size of coal fragments by crushing in a vacuum might, in some similar way, allow the evolution of gas which was not possible from the lump coal. But as the lumps of coal are only crushed down to a coarse powder it would not seem as if truly occluded gas should

[a] Moissan, Chimie minérale, vol. 5, p. 860.
[b] Graham, Chemical and physical researches, pp. 283-290.

be freed, to any large extent, by the coal crusher, even in a vacuum. If crushed under full atmospheric pressure in an inert gas, no occluded gas should be liberated. It is not at all certain that coal behaves like palladium in these matters. It seems, therefore, safer to conclude that by crushing the coal and opening up many pores and cavities it is chiefly the imprisoned cavity gas that is liberated.

METHOD OF CRUSHING.

The apparatus for crushing the coal was constructed on the principle of the familiar steel mortar, fitted with a long piston rod incased in a heavy rubber tubing, which, with one end fastened to a flange at the top of the mortar cylinder and the other wired to the piston rod near its free end, makes an air-tight connection, and at the same time renders the piston movable. A few vigorous blows delivered with a heavy mallet upon the end of the piston rod serve to crush the coal, after which the gas liberated during the crushing is pumped out of the cylinder through a short delivery tube, fitted with a stopcock.[a] The apparatus is intended to maintain a complete vacuum for the short time required to crush a sample of coal, but in practice it was found advisable, in order to prevent a slight inleaking of air, to place the cylinder of the crusher in a pail of water during the operation. This crusher was able to pulverize from 50 to 100 grams of coal at a time. The coal was crushed both in a vacuum and under full barometric pressure.

DETAILED RESULTS.

Sample 1.—Coal collected on December 13, 1907, from the face of No. 4 right entry, off the F-face heading, mine No. 6, Monongah, was crushed in a vacuum on January 27, 1908. Starting with lumps of coal of about 1 cubic inch, the material was crushed twice, the crusher being opened after the first crushing and the finer dust sifted out. The extent to which the coal was reduced after both crushings was determined by sieves, as follows: Of 100.21 grams of coal used, 20.56 grams passed through a 30-mesh sieve, 31.26 grams passed through a 10-mesh sieve, and 48.39 grams was too coarse to pass the 10-mesh sieve. There was obtained 10.57 cubic centimeters of gas at 0° C. and 760 millimeters pressure, having the following composition:

Analysis of gas obtained by crushing coal sample 1.

	Per cent.
Carbon dioxide	2.90
Methane	39.65
Oxygen	10.07
Nitrogen	38.11
Nitrogen (excess)	9.27
	100.00

[a] This rock crusher has been described in detail, with a diagrammatic sketch in The gases in rocks: Carnegie Institution of Washington, Pub. No. 106, p. 39.

If the gas all came from the coal which passed through the 30-mesh sieve, the methane would amount to 0.26 of the volume of that coal. But if to this coal be added that which passed the 10-mesh sieve, the methane is only 0.10 of the volume. The latter figure is to be preferred.

Sample 2.—Coal collected December 12, 1907, from room 3 on third right, off second north heading, mine No. 8, Monongah, was crushed in a vacuum January 28, 1908. Two lumps of coal were pulverized, in two crushings, to the following degree of fineness: Of 49.13 grams in all 20.24 grams passed through the 30-mesh sieve, 23.67 passed through the 10-mesh sieve, and 5.22 grams was too coarse to pass the 10-mesh sieve. The crushing liberated 11.71 cubic centimeters of gas at 0° C. and 760 millimeters pressure, which had the following composition:

Analysis of gas obtained by crushing coal sample 2.

	Per cent.
Carbon dioxide	1.56
Methane	40.99
Oyxgen	9.86
Nitrogen	37.62
Nitrogen (excess)	10.27
	100.00

The quantity of methane is equivalent to 0.30 of the volume of the coal which passed the 30-mesh sieve, to 0.14 of the volume of the 10-mesh coal, and to 0.12 of the volume of all the coal used.

A duplicate test with this same sample of coal, crushed in three trials, afforded the observation that there is not any very noticeable slackening in the gas obtained from the second and third crushings. For the first trial the total weight of coal is used. After the gas has been pumped over into the receiver, the crusher is opened and the fractured coal sifted with both the 10-mesh and 30-mesh sieves. Only the coal coarser than the 10-mesh sieve is returned to the cylinder of the crusher for the second trial. The second trial thus crushes coal fragments averaging about the size of a bean to fine 10-mesh coal and dust, and as it crushes about the same weight fine enough to pass through the sieves as did the first trial, it is to be expected that about the same volume of methane will be obtained. After the second trial the coal is again sifted and that portion which is too coarse to pass through the 10-mesh sieve is put back into the crusher for the third trial. It is clear that some of the gas comes from that coal which is partly crushed, though not fine enough to go through the 10-mesh sieve, but in estimating the volume of gas given off per unit volume of coal it seems advisable to consider only that coal which has passed through the sieves, for whatever gas may have come from the coarser coal would undoubtedly be offset by the gas still remaining in the fine coal. Crushing coal to 30-mesh does not remove all the gas.

In the experiments with samples 1 and 2 the coal was crushed in a vacuum and the gas brought out under reduced pressure. To ascertain the part played by low pressure in this process of gas extraction, and hence whether much gas escaped from occluding bonds, samples of coal were crushed under the full barometric pressure, both in air and in an atmosphere of carbon dioxide.

Sample 3.—Coal from the same can as sample 1 (p. 18) was crushed in air under full barometric pressure. As it was necessary in this experiment to discover how much methane is liberated solely by crushing the coal, without the cooperation of a reduction in pressure, the gas was removed from the crusher in two portions. The first portion consisted of the air and gas which was removed by the first stroke of the vacuum pump. The stopcock being open only about two seconds, and only about half the contents of the crusher being removed, whatever methane was found in this portion must have been freed from the coal without the influence of reduced pressure. As soon as this portion could be stored away for analysis, the remaining gas was rapidly pumped out of the crusher. These two portions were analyzed as follows:

Gases removed after crushing coal sample 3 in air, with their relation to the coal by volume.

Gas.	First portion.			Second portion.		
	Per cent.	Ratio to volume of coal as 1.		Per cent.	Ratio to volume of coal as 1.	
		30-mesh.	10-mesh.		30-mesh.	10-mesh.
Carbon dioxide	0.16	0.016	0.007	0.27	0.026	0.012
Methane	3.68	.35	.17	4.61	.45	.21
Air	96.16	9.31	4.34	95.12	9.23	4.31
	100.00	9.68	4.51	100.00	9.70	4.53

As would naturally be expected, the percentage of methane is higher in the second portion than in the first, though the difference is not great. But the greater amount of methane in the second portion was not liberated entirely through the influence of reduced pressure, as the fine coal had stood longer in the second case than in the first, and the element of time proves to be an important factor in the escape of gas from coal.

However, only the first portion is to be taken as representing the gas liberated during the crushing under full atmospheric pressure. An estimate of the total volume of gas obtained from the crusher on the basis of the analysis of the first portion gave the first two columns of the following table. A comparison of these figures with those in the last two columns, obtained by combining the volumes of the two portions analyzed separately, may help to show how much gas may be attributed to the reduced pressure.

Relation to the coal by volume of gases removed after crushing coal sample 3 in air.

[Ratio to volume of coal as 1.]

Gas.	Estimate based on first portion.		Total for the two portions as analyzed.	
	30-mesh coal.	10-mesh coal.	30-mesh coal.	10-mesh coal.
Carbon dioxide	0.031	0.014	0.042	0.019
Methane	.71	.33	.80	.38
Air	18.65	8.69	18.54	8.65
	19.39	9.03	19.38	9.04

The confirmatory tests were made with other samples of coal from Monongah mine No. 6. Sample 4 was collected December 16, 1907, from the face of the east returning air way, and crushed March 10, 1908. Sample 5 was collected December 13, 1907, from the face of the H manway, and crushed March 18, 1908. Each of these samples was crushed in air under barometric pressure, and the gas removed in two portions. For each sample the total volume of methane was calculated for both portions of gas, on the basis of the analysis of the first portion, which came over with the first stroke of the pump. At least this calculated amount of methane must have come off without the aid of reduced pressure. Expressed in terms of the volume of coal which was crushed down to 30-mesh, the amount for sample 4 was 0.27, and for sample 5, 0.79. The volume of methane actually obtained for the two portions was, in the same terms, 0.41 for sample 4 and 0.86 for sample 5.

In the test of sample 5 the difference between the total volume of methane actually obtained and the calculated volume which must certainly have been liberated from the coal under full barometric pressure is small. Moreover, only a portion of this small difference can be attributed to the effect of reduced pressure, as other factors, such as slow diffusion and the greater interval of time, have helped to cause this difference.

For a series of systematic experiments to show the amount of methane which is liberated from the same coal under various conditions, the can of coal which was collected from the face of the H manway in Monongah mine No. 6 was selected (sample 5). The results of crushing lumps of this coal are as follows, the several tests being set forth in numbered paragraphs, with the volume of methane expressed in terms of the volume of coal crushed to 30-mesh and to 10-mesh:

1. Coal was crushed in a vacuum, but so much water vapor was given off and drawn past the calcium chloride drying tube into the pump that in order to draw over all the gas it was necessary to keep the pump going for nearly one hour. Hence the time factor enters here. Ratio, by volume, of methane to 30-mesh coal, 0.88; to 10-mesh coal, 0.33.

2. Coal crushed in a vacuum and the gas immediately pumped off. Then a full atmosphere of carbon dioxide was run in and pumped out, bringing with it the last traces of methane. Two separate trials were made, giving ratios of 0.89 and 0.83, respectively, to 30-mesh coal, and 0.38 and 0.34 to 10-mesh coal.

3. Coal was crushed in a vacuum, but phosphorus pentoxide was used as a drying agent instead of calcium chloride. Ratio of methane to 30-mesh coal, 0.84; to 10-mesh, 0.33. After pumping out this gas and removing it for analysis, an atmosphere of carbon dioxide was run in as rapidly as the apparatus could be manipulated, and then pumped out again quickly, and the gas collected over a 30 per cent solution of potassium hydroxide. More methane came over, some, and perhaps most, of which is to be explained by the time consumed in the carbon dioxide treatment. The amount was 0.14 of the volume of 30-mesh coal, and 0.05 of the 10-mesh coal.

4. Coal crushed in air under barometric pressure. This test has been described on page 21 (sample 5). The amount of methane was 0.86 of the 30-mesh coal and 0.41 of the 10-mesh.

5. Coal crushed under barometric pressure in an atmosphere of pure carbon dioxide. Amount of methane, 0.91 of the 30-mesh coal, 0.44 of the 10-mesh.

Tests 6 and 7 were made to determine the influence of the length of time during which the coal is allowed to stand after crushing, upon the quantity of gas given off.

6. Coal crushed in a vacuum and allowed to stand 3½ hours with occasional pumping. Then the apparatus was filled with carbon dioxide and pumped out again. Total duration of the experiment, 4 hours; considerably more gas was thus obtained than when the process was completed in less than 1 hour. Analyzed in four separate portions. The total methane was 1.38 times the volume of 30-mesh coal, and 0.57 of the 10-mesh.

7. Coal crushed in a vacuum. Pumping kept up for 1 hour; then, after a short time, 30 cubic centimeters of hydrogen were let in and soon pumped out. After another 1½ hours an atmosphere of carbon dioxide was run in and pumped out again. Duration of experiment, 4 hours. Analysed in three portions. Total methane, 1.39 times the volume of 30-mesh coal, and 0.53 of the 10-mesh.

These last two experiments, in which the totals include all the methane which escaped from the coal during four hours after the process of crushing, show that the gas does not all escape from the coal within the first few minutes after the coal is shattered, and that to obtain comparative results it is necessary that the time consumed during the process of removing the gas after the coal has been crushed be approximately the same in all tests. In the last test the gases pumped off during the first hour, those brought over by the hydrogen, and those which came with the carbon dioxide, were collected and analyzed separately, but nothing of significance was developed except, perhaps, the fact that the hydrogen treatment yielded somewhat less methane than had been anticipated.

These experiments, taken as a whole, appear to indicate that, in respect to the volume of methane obtained from the coal, it makes little difference whether the coal is crushed in a complete vacuum, or under the full barometric pressure, in an atmosphere either of air or of carbon dioxide, provided the gas in each case is quickly pumped out of the crushing apparatus. Gas continues to escape from the

crushed coal at a rather rapid rate for some time after it has been crushed, but this feature will be considered elsewhere.

The quantity of gas immediately liberated from the coal when it is broken up is thus largely independent of the outside pressure. Such gas, therefore, can not be supposed to have come directly from a state of occlusion, for, without an appreciable change either of temperature or pressure, occluded gas should not be given off in this way, even from finely divided coal. Nor can it come immediately from chemical decomposition of the nongaseous constituents of the coal. It must, instead, have been already stored within the mass of the coal as free gas, mechanically imprisoned in numerous pores, cavities, and crevices, from which much of it is immediately released as soon as the confining walls are shattered in the process of crushing, and the pores and cavities opened to the surface. Necessarily, in the process of crushing to this state of fineness, only a portion of the gas-holding pores are so opened as to enable the inclosed gas to escape at once. In many others, the shattering makes it possible for the gas to escape by slow diffusion, where before it was securely held. Hence an abnormally rapid escape of gas follows for a short period of time after the coal has been crushed.

However, it is not impossible that in those tests in which the coal was crushed in a vacuum or practical vacuum, the reduced pressure, acting on the fresh surfaces of the crushed coal, might have caused the escape of some truly occluded gas. If such gas escapes from the coal, it would be likely to come largely from that portion which was most finely pulverized. (See p. 17.) But quantitatively this occluded gas can not play a very important part in the gas liberated by crushing the coal, as its liberation is dependent on a reduction of pressure, and these experiments indicate that, in the volume of gas given off, it makes little difference whether the coal is crushed under the full barometric pressure or in a complete vacuum. Thus, while there is a possibility, and even a probability, that some of the gas does come from a state of occlusion, it seems more plausible to regard the main bulk of the gas escaping from coal during the process of crushing, and at an abnormal rate just after being crushed, as being cavity gas, whose escape is facilitated by the shattering which the crushed coal fragments have received. The fact that the presence of oxygen, nitrogen, hydrogen, or carbon dioxide in the crusher has little influence on the amount of methane given off during the crushing, and for a short length of time afterwards, is in harmony with the theory that this gas escapes largely from mechanical bonds.

GASES FROM COAL BOTTLED IN A VACUUM.

VACUUM BOTTLES.

The experiments with the coal crusher have shown how much gas can be liberated from these coals by crushing them to a certain degree of fineness and opening up many of the gas-holding pores. But this process does not remove all the gas, nor is it the only way to extract the gas from coal without the use of heat. To get the gas which slowly escapes from coal, different samples of coal were stored in vacuum bottles, from which the gas evolved was pumped out from time to time. Each of these bottles had a capacity of 500 cubic centimeters and was fitted with a one-holed rubber stopper containing a short delivery tube. Over the free end of the delivery tube was slipped a short piece of heavy antimony rubber pressure tubing, which serve to make the connection with the mercury pump. A strong screw clamp on the rubber tubing closed the way to the bottle. The stopper and rubber connections were all coated with paraffin to prevent leakage of air. When the air from the bottle had been completely exhausted, the clamp upon the rubber tube was tightly screwed, the rubber tube disconnected from the pump, and a plug of glass rodding quickly run into the rubber tube as far as the screw clamp would permit. Rendered tight by paraffin the bottle was submerged in a jar of water until the time came to remove the gas. At any time desired the bottle could be connected with the mercury pump and the gas which had accumulated removed for analysis, after which the bottle was again submerged in the water jar.

VOLUME OF GAS.

The volume of the gas extracted from coal by allowing it to remain in an essential vacuum for a period of time was somewhat variable and depended on the sample of coal, the interval of time between its removal from the coal seam and its confinement in the vacuum bottle, the size of the coal fragments, and the duration of the experiment. The finer the coal the more rapidly and completely was the gas liberated in a given period of time. At the end of six months gas was still accumulating steadily in those bottles which contained lump coal, and it was only in those containing crushed coal that the escape of gas had nearly ceased. The volume of gas from the crushed coal ranged from 0.9 to 2.3 times that of the coal from which it came. The lump coal yielded gas to the extent of 0.5 to 0.9 of its own volume during half a year at low pressure. Because of the pressure of other laboratory experiments, and the time required for the inspection of the Darr mine shortly after the material was collected at Monongah, more than a month elapsed between the collection of the coal samples and the bottling of them in a vacuum. These figures, therefore, do

not represent all the methane given up by the coal since its removal from the seam, for a certain quantity of the gas may be supposed to have escaped while the coal was in the collecting cans.

To obtain data on the volume of gas lost during the first month after the removal of the coal from the seam, samples of fresh coal were collected in the usual cans, which were at once hermetically sealed with a thick coating of paraffin, before leaving the coal face. When opened in the laboratory about a week later, a determination of the gas in the cans was made, after which some of the coal was immediately placed in the vacuum bottles. In this way all the gas escaping from the coal after the sample was mined at the working face was determined. A specimen of bituminous coal in the form of lumps from the Mansfield mine at Carnegie, Pa., gave off 0.55 of its volume of gas, exclusive of nitrogen, during seven days in the collecting can and thirty days in the vacuum bottle. Analyses made at intervals during this length of time indicated that gas was freed much more rapidly during the first few days after collecting than later. But a similar experiment with gassy anthracite coal showed only a slight slackening in the rate of methane escape, and this change in the rate was almost uniformly distributed throughout the period of observation.

CHARACTER OF GAS.

The coal thus bottled in a vacuum was kept under observation for a period of half a year, during which time the bottles were connected with the mercury pump at stated intervals and the gas which had accumulated was removed for analysis. Thus not only was the rate at which the gas escaped from the coal discovered, but the character of the gas evolved throughout this length of time was determined. However, as the principal object of the experiments in which these vacuum bottles were employed was to determine the volume of methane escaping from the coal during a given interval of time, less care was given to the determination of the minor constituents, especially carbon monoxide and the ethylene series. In some tests the absorption of the olefins with fuming sulphuric acid, or bromine water, was omitted, and the gases of this series were removed, together with carbon monoxide, by cuprous chloride. Also, the leakage of small quantities of air into the vacuum bottles was not prejudicial to the chief purpose of the experiments, for the volume of methane was in no way affected. Although these analyses are subject to these limitations, they yet serve to indicate pretty closely the general character of the gas which escaped from the coal during the period of half a year under reduced pressure. Four of these sets of analyses of the gas from coals are given in the table following.

Analyses of gases escaping from small lump coal bottled in a vacuum, with relation to the coal by volume.

[Figures of analyses show percentage.]

EXPERIMENT A.[a]

Gas.	3 weeks after bottling.	4 weeks later.	10 weeks later.	9 weeks later.
Carbon dioxide	2.07	3.00	2.72	2.95
Carbon monoxide / Olefins	.32	.07	.65	.84
Paraffins	35.51	69.10	76.05	84.38
Air: Oxygen	.39	.....	.08	.38
Air: Nitrogen	1.47	.....	.30	1.44
Nitrogen (excess)	59.77	27.83	20.20	10.01
	100.00	100.00	100.00	100.00
Relative volume	.17	.11	.13	.09

[a] Coal from the face of the east return air way in Monongah mine No. 8. The rate of the escape of the gas from this coal is expressed by curve 5 in fig. 1.

EXPERIMENT B.[a]

Gas.	3 weeks after bottling.	4 weeks later.	10 weeks later.	9 weeks later.
Carbon dioxide	1.05	0.83	0.63	0.60
Carbon monoxide / Olefins	1.03	.29	.84	1.13
Paraffins	55.37	84.96	91.39	87.89
Air: Oxygen	.51	.35	.50	.40
Air: Nitrogen	1.91	1.32	1.89	1.51
Nitrogen (excess)	40.11	12.25	4.75	8.47
	100.00	100.00	100.00	100.00
Relative volume	.21	20	.28	.21

[a] Coal from the face of the right main in Naomi mine. The rate at which this coal evolved gas is given by curve 6, fig. 1.

EXPERIMENT C.[a]

Gas.	First 10 days.	Second 10 days.	Third 10 days.
Carbon dioxide	8.88	13.52	12.34
Carbon monoxide	.....	.....	.22
Olefins	.....	.82	.....
Paraffins	82.00	72.15	84.44
Air: Oxygen	.55	1.35	.58
Air: Nitrogen	2.08	5.11	2.19
Nitrogen (excess)	6.49	7.05	.23
	100.00	100.00	100.00
Relative volume	.31	.15	.12

[a] Coal from the face of room 21, on No. 4 southeast butt, off No. 6 face entry, Mansfield mine at Carnegie, Pa.

EXPERIMENT D.[a]

Gas.	First week.	Second week.	Third week.	Fourth week.
Carbon dioxide	0.02	.....	0.17	.....
Carbon monoxide	.....	.....	.....	.....
Olefins	.51	0.78	.87	0.29
Paraffins	86.86	93.99	94.19	98.58
Air: Oxygen	.04	.....	.....	.07
Air: Nitrogen	.15	.....	.....	.26
Nitrogen (excess)	12.42	5.23	4.77	.80
	100.00	100.00	100.00	100.00
Relative volume	1.22	.99	.89	.81

[a] Anthracite coal from the face of slope of gangway east of No. 30 tunnel, No. 1 north shaft, at Nanticoke, Pa.

The analyses of the gas from the other samples of Carboniferous coal which were subjected to this same treatment show similar results.[a] The most noteworthy change in the nature of the gas escaping from the coal during the period of observation was the steady decrease in the proportion of nitrogen and the corresponding increase in the percentage of methane. Much of the nitrogen that appeared in the portion of gas removed from the bottles at the end of the first three weeks doubtless came from air which adhered to the coal or was absorbed by its mass, and was not given off immediately when the vacuum was produced. As the oxygen which coal absorbs enters rapidly into chemical union with the substance of the coal, the latter respires chiefly nitrogen (with some carbon dioxide) in place of the air taken in. The influence of the nitrogen from the air is naturally most felt during the early part of the sojourn of the coal in the vacuum bottles, as this nitrogen is largely held by the surface layers or in the more prominent crevices and lines of fracture. It therefore escapes from the coal more readily than the gas originating in the coal, which is distributed throughout its mass, but most abundantly in the interior of the fragments, from which escape is slow and difficult. As this extraneous nitrogen was removed, the percentage of the methane rose proportionately.

Methane was quantitatively by far the most important gas which escaped from the bottled coal. After the extraneous nitrogen had been removed, it ran in some tests as high as 98 per cent of all the gas coming from the coal. More commonly, however, it constituted from 80 to 95 per cent of the gas liberated. Methane reached its highest percentage in the gas from anthracite coal, which yielded only small proportions of the other constituents, carbon dioxide and nitrogen.

In addition to methane, at least one other higher member of the paraffin series was found. In nearly every analysis the explosion of the residual gas with oxygen, after the removal of the absorbable gases, produced carbon dioxide in slight excess over what would have resulted from the combustion of methane alone. Calculations show that the excess of carbon dioxide noted can be explained by the presence of ethane in proportions of a trace to 4 parts of C_2H_6 to 100 parts of CH_4. Other higher paraffins may be present in small quantities, but the computations are made on the basis of ethane alone, as $C_3H_8 + CH_4 = 2C_2H_6$. So far as the tests have been carried, the bituminous coal has yielded more ethane than the anthracite (one sample only). In fact, in several tests the explosion of anthracite gas, instead of indicating higher paraffins, suggested the presence of a small amount of hydrogen.

[a] The Cretaceous coal from, New Mexico, however, behaved differently (giving 30 to 40 per cent carbon dioxide and only 4 per cent methane), but that is outside the field of this report.

Carbon dioxide was found to be a more variable constituent of the gas, depending on the nature of the coal from which it came. The various experiments with the Monongah coal show that in most of the samples it amounted to 1 to 3 per cent of the gas which accumulated in the bottles. In the bituminous coal from the Mansfield mine at Carnegie, Pa., carbonic anhydride became much more important, reaching 13 per cent of the total gas given off. But on the other hand, careful analyses made over mercury failed to detect any carbon dioxide in two out of the four portions of gas from the anthracite coal of Nanticoke, while the analyses of the other two portions revealed the presence of only small quantities of this gas. Although the proportion of methane steadily increased as the experiment progressed, in general the proportion of carbon dioxide fluctuated during the period of observation.

The volume of nitrogen in the bottles fell rapidly during the progress of these experiments. Apparently much of the nitrogen which was obtained from coal by this and other methods, especially that portion of the gas which came off most readily, is not to be regarded as gas held by the coal while in the undisturbed strata, but as nitrogen absorbed by the coal after it became exposed to the air in the mining operations. Some of it was derived from air adhering to the coal and tubes in spite of the effort of the mercury pump to remove it. The leakage of air into the bottles could take place only while they were out of the water jar and connected with the pump. Hence, most of whatever inleaking air there may have been was quickly pumped over into the gas receiver with the rest of the gas, and was determined in the analysis on the basis of the amount of oxygen found. Only such air as could leak into the bottle, between the closing of the screw clamp and the immersion of the bottle in the water jar after sealing the rubber-tube connection with glass plug and paraffin coating, could remain in the bottle with the coal during the interval between tests. Absorption of oxygen from such air by the coal would leave an excess of nitrogen in the gas. But as less than one minute elapsed between the closing of the screw clamp and the immersion of the bottle, the amount of leakage was reduced to a small figure. The excess of nitrogen in the analyses of the portions of gas taken at the end of the half-year period indicated that the coal did contain nitrogen as a truly original gas. This may have come originally in part from air buried with the accumulated vegetable matter and in part from the decomposition of nitrogenous compounds in the organic matter whose metamorphism produced the coal.

The minor constituents of the gas from coal were carbon monoxide and one or more members of the olefin series, most probably ethylene.

The above figures represent the character of the gas escaping from lumps of coal averaging somewhat less than a cubic inch in size. The

evolution of gas had in no case ceased at the end of the six-months period. Instead, gas was still steadily accumulating in the bottles, though at a diminishing rate. The composition of the last portion of the gas which would eventually escape, if the experiment were carried on for a much longer period, can only be inferred from these experiments with the lump coal. However, from the studies on the finely crushed coal, from which the gas escaped much more rapidly and completely in a given length of time than from the coarser fragments used in the above tests, more can be learned on this question. Two representative experiments with coal crushed in the rock crusher so as to pass through a 10-mesh sieve, and then bottled in a vacuum, may be selected to illustrate the composition of the gas which came from the coal after the main bulk of the free gas had been liberated and the outflow had nearly ceased.

Analyses of gases escaping from crushed coal bottled in a vacuum, with relation to the coal by volume.[a]

EXPERIMENT E.[b]

Gas.	First 6 weeks.		Next 10 weeks.		Next 10 weeks.	
	Percentage.	Relative volume.	Percentage.	Relative volume.	Percentage.	Relative volume.
Carbon dioxide	2.00	0.019	0.82	0.002	15.27	0.018
Carbon monoxide	.20	.002	.16	.....	2.86	.004
Olefins	.29	.003	.27	.001	.55	.001
Paraffins	55.99	.542	64.31	.169	47.31	.058
Air {Oxygen	.18	.008	8.56	.022	2.70	.019
Air {Nitrogen	.68		25.88	.068	12.91	
Nitrogen (excess)	40.66	.393	.....	.....	18.40	.022
	100.00	.967	100.00	.262	100.00	.122

[a] The first analysis in each of these tables was made by the usual technical method of Hempel; the last two analyses in each case were made over mercury with the apparatus described by Bone.

[b] Coal from the face of fourth right entry off F face heading, Monongah mine No. 6, crushed and passed through a 10-mesh sieve. The rate of evolution of methane is shown by curve 2 of fig. 1.

EXPERIMENT F.[a]

Gas.	First 2 weeks.		Next 10 weeks.		Next 14 weeks.	
	Percentage.	Relative volume.	Percentage.	Relative volume.	Percentage.	Relative volume.
Carbon dioxide	2.28	0.019	4.35	0.011	20.77	0.034
Carbon monoxide / Olefins	.79	.007	1.54	.004	13.35	.022
Paraffins	62.57	.535	30.51	.076	41.77	.069
Air {Oxygen	.12	.005	[b] 12.38	.148	.15	.....
Air {Nitrogen	.45		[b] 46.85		.57	.....
Nitrogen (excess)	33.79	.290	4.37	.011	23.39	.038
	100.00	.856	100.00	.250	100.00	.163

[a] Coal from the face of H manway in Monongah mine No. 6, crushed so as to pass through a 10-mesh sieve, and then quickly placed in the vacuum bottle. The rate of methane liberation is shown by curve 7 of fig. 1.

[b] While the gas was being pumped out a leak unfortunately appeared in the tubing connecting the vacuum bottle with the exhaust pump.

According to the foregoing table the relative proportion of both carbon dioxide and carbon monoxide increased greatly during the last weeks of each experiment, chiefly in consequence of the rapid slackening in the output of methane. This gas, because it diffuses and transpires at more rapid rates than the other gases mentioned, escaped from the coal sooner than the less active molecules, and hence the stored-up supply of free methane in the coal was more quickly depleted than that of carbon dioxide. Thus, on theoretical grounds, the coal may be expected to give off carbon dioxide for a longer period than methane. But these tables not only indicate an increase in the relative proportion of carbon dioxide and carbon monoxide during the latter part of the experiment, but they appear to show also an absolute increase in the volume of the oxides of carbon evolved per unit of time. During the first few weeks after the coal was bottled in a vacuum there was a reduction in the rate of outflow of all the gases, but during the last ten weeks of the half-year period the evolution of the oxides of carbon apparently proceeded at an accelerated rate. This feature was most conspicuous in experiments E and F, but the same phenomenon was also shown, though in a less striking manner, in the results of the two other similar series of analyses which furnished the data for curves 4 and 8 of figure 1.

The experiments with the rock crusher indicate that a large part of the free gas held by coal is mechanically imprisoned, under pressure, within the pores, interstices, and lines of fracture of the coal. Such gas is released immediately when the coal is pulverized and many of the gas-holding cavities are broken open. Many of the pores charged with gas are not opened by the crushing process, so that much cavity gas still remains in the crushed coal. Of the gas exhaled when the coal is placed in a vacuum, it seems safe to assign the bulk of the methane, carbon dioxide, and other gases which escape from the coal, rapidly at first, but at a progressively declining rate, to this mode of occurrence. The gases under pressure in the interstices of the coal are supposed to reach the surface by diffusion, or more strictly, transpiration, and to escape until in time the gas thus mechanically held has bled itself out. The curves showing the rate of escape of methane support this view in regard to that gas. But the behavior of carbon dioxide and carbon monoxide in this respect appears to be different. The declining volumes of these gases during the first few weeks are natural enough, as the cavity gas comes off in greatest volume immediately after the coal is crushed. But reasons for the apparently increasing volumes toward the end of the experiments are less easily found. Possibly the increment of carbon dioxide and carbon monoxide may come from a state of occlusion. Charcoal, which is like coal, is known to absorb the

oxides of carbon in much greater volume than hydrogen[a] and probably also in greater volume than methane, though the figures for the latter are not at hand. The presumption, therefore, is that of the coal gases the oxides of carbon are likely to be held in greatest volume as occluded gas. But why such gas, even if occluded, should be liberated most rapidly after so long an interval is not apparent at the present time. Perhaps the explanation is to be found in chemical changes. For the present, however, the cause of this phenomenon must be left open. Further experimentation, to determine how generally the rule is true of different coals, is necessary before more is made of this point.

COMPARISON WITH MINE GASES.

To make a comparison between the composition of the gas which escapes from the bottled coal in the laboratory, and that which issues from the rock strata, a few analyses of feeder gas from the mines may be introduced:

Analyses of feeder gas.

Number.	CO_2.	CO.	C_nH_{2n}.	CH_4.	H_2.	Air.	N_2 (excess).
1	1.45	.....	.09	50.67	.....	29.33	18.46
2	1.37	.03	.....	31.99	.....	58.32	8.29
3	2.04	.....	.20	90.42	.....	6.02	1.32
4	2.39	.26		92.17	.....	2.63	2.55
5	1.59	.04	.49	91.31	.82	1.10	4.65

1. Accumulation of gas at roof 20 feet from face of swamp entry, Darr mine.
2. Gas and air from drill hole in the face of right air course of main entry, Darr mine.
3. Feeder on eighth right entry, off main southwest entry, Cardiff mine, Cardiff, Ill.
4. Feeder on main southwest entry in Cardiff mine.
5. Gas issuing under high pressure from standpipe at surface 100 yards southeast of railroad station, at Luzerne (near Wilkesbarre), Pa., from anthracite coal.

The presence of a higher member of the methane series, probably ethane, was noted in Nos. 1, 3, and 4, but the paraffins have here been computed as so much methane. In No. 5, after the removal of the hydrogen by palladium, the explosion indicated only methane.

A comparison of the foregoing table with that on page 26, after the proper allowance is made for air and nitrogen absorbed from the air by the coal used in the laboratory experiments, fails to show any significant difference between the feeder gas encountered in the mines and the gas extracted from lumps of coal in the laboratory by means of a vacuum. But a comparison with the table on page 29 shows that, while the feeder gas bears a close resemblance to the gas which is obtained from the finely crushed coal during the first few weeks under reduced pressure, it is quite different from the gas which is finally exhaled from the fine coal after it has stood some months

[a] Moissan, Chimie minérale, vol. 2, pp. 251-253.

and has lost the bulk of its free gas. The feeder gas does not contain the high percentages of carbon dioxide and carbon monoxide which characterize the last gas to escape from the fine coal. Feeder gas therefore represents that portion of the gas which is first to escape from the coal and which comes out most readily. It would seem to be that portion of the gas which, having been mechanically held at the outset in the interstitial spaces throughout the mass of the coal stratum, has subsequently escaped from the scattered pores in the coal and has accumulated along more or less connected lines of fracture, or other places of weakness or increased porosity. Traveling along these, it now issues into the mine workings from distinct orifices, cracks, or localized portions of the coal bed, at a more rapid rate and in greater volume than it is elsewhere exhaled from the solid coal.

Necessarily the issuance of gas in the form of feeders, under pressure, must die out long before the steady exhalation from the body of the coal, though the same lines of fracture continue to serve as paths of discharge for the gases slowly but steadily gathering in the porous reservoirs back in the coal. And to judge from the slowness with which even small lumps of coal manifest a change in the character of the gas transpiring from them, even when favored by a reduction of pressure, it would seem that a very much longer period of time would be required to produce the change in composition which the behavior of the finely crushed coal suggests will ultimately occur in the gas freed from the solid coal.

But in the case of pillars and other coal surfaces long exposed to the the weathering action of the mine air, there enters another factor which is absent in the vacuum-bottle experiments,—that is, the steady oxidation of the coal by the oxygen of the air. Experiments on coal bottled in air, under ordinary barometric pressure, show that oxygen is rapidly absorbed by the coal until, after a few days, there remains often only 1 or 2 per cent of oxygen in the free gas in the bottle. At the same time a certain proportion of the oxygen uniting with the coal comes off again as carbon dioxide, but this, at least during the short time of the experiment, amounts to only a small part of the oxygen entering the coal. Perhaps with an abundance of air and a much longer period of time, so as to allow the coal to absorb oxygen to its full capacity, a much larger proportion of it might eventually reappear from the saturated hydrocarbon compounds, as carbon dioxide.

The feeder gas originates back in the coal seam, away from the influence of the air, and hence it does not contain carbon dioxide from the direct oxidation of the coal. But the exposed coal surface must produce carbon dioxide in this way and thus supply the mine air with

carbonic acid, which, though coming from the coal, is largely independent of the free gas content of the coal. This property appears to vary in different coals. The gassiness of a certain coal is not necessarily an index to the volume of carbon dioxide which may be developed from it as a contribution to the mine air. A few analyses made in Germany of the air from unexploded mines indicate a higher proportion of carbon dioxide, in comparison with methane, than is found in the feeder gas, suggesting that the oxidation of the coal may be a more prolific source of the carbon dioxide encountered in the mines than the outflow of the free gas stored within the coal.

RATE OF ESCAPE.

The samples of coal were kept in the vacuum bottles for twenty-six weeks, or just half a year. At stated intervals during this time the gas which had accumulated was pumped out and analyzed. As methane was by far the most abundant gas thus obtained, as well as the most important from the standpoint of this investigation, the volumes of that gas given off per unit volume of coal were taken as the standard. Curves were plotted, as in figure 1, to show the rate of escape of this gas from the coal, the ordinates of the graph representing the relative volumes of methane, and the abscissas expressing the progress of time in weeks.

Descriptions of the samples of coal and the conditions from which the several curves were plotted follow:

Curve 1. Methane from coal collected from the face of the fourth right entry, off the F face heading, in mine No. 6, at Monongah, December 13, 1907; bottled in vacuum January 23, 1908.

Curve 2. Same coal as No. 1. Crushed in vacuum on January 27 by means of coal crusher, and then placed in the vacuum bottle.

Curve 3. Methane from coal collected from room 3 on third right off second north heading, in mine No. 8, at Monongah, December 12, 1907; bottled in vacuum January 23, 1908.

Curve 4. Same coal as No. 3. Crushed in vacuum in coal crusher January 28, and then placed in the vacuum bottle. Coal passed through 30-mesh sieve.

Curve 5. Coal from the face of the east return air way in mine No. 8, Monongah. Collected December 17, 1907; bottled in vacuum February 10, 1908.

Curve 6. Coal from face of right main, Naomi mine. This is the most gassy point seen in the mine. Collected December 14, 1907; bottled February 11, 1908.

Curve 7. Coal from face of H manway, mine No. 6, Monongah. Collected December 13, 1907; crushed in vacuum March 17, 1908, and immediately placed in vacuum bottle.

Curve 8. Same coal as No. 7. Crushed in air under full barometric pressure on March 18, 1908, and immediately placed in vacuum bottle.

Curves 1, 3, 5, and 6 show the escape of methane from lumps of coal averaging approximately the size of a marble. Curves 2, 4, 7, and 8 indicate the volume of gas which escaped from coal crushed so

that all of it would pass through a 10-mesh sieve, a considerable part of it being necessarily much more finely reduced than this.

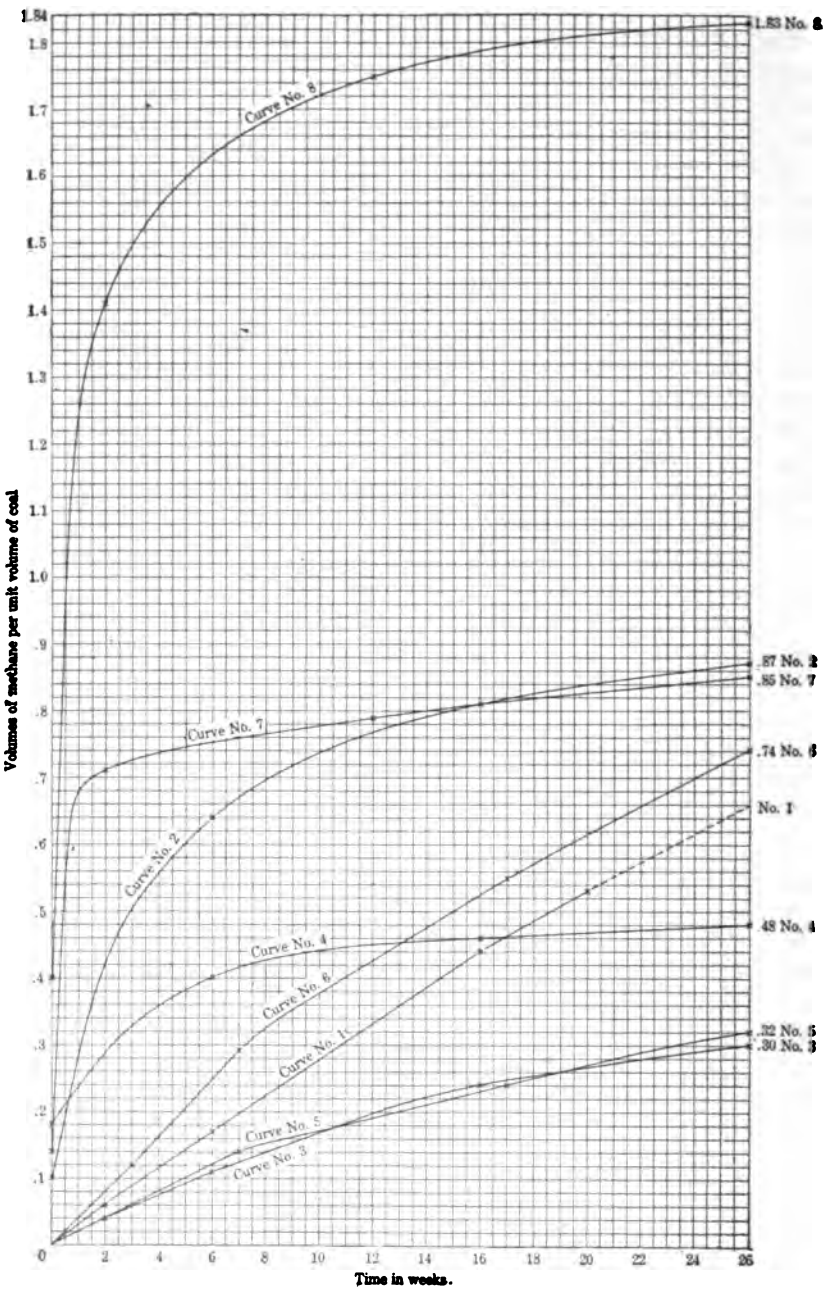


FIGURE 1.—Diagram showing rates of escape of methane from coal. (For explanation see text, p. 33.)

The volumes of methane liberated during the process of crushing are also included in these curves. Hence curves for the crushed coal

instead of commencing at the zero point start at points on the vertical axis corresponding to the volume of methane lost during the process of crushing.

The four curves representing the lump coal show that the escape of methane from fragments of coal, even in a vacuum, takes place slowly and steadily and must in some cases continue for a very long period of time. Curve 1 is nearly a straight line, showing that the evolution of methane was nearly as rapid at the end of twenty weeks as when the coal was first placed in the vacuum. In the other three experiments the rate of escape declined more rapidly.

The relation between the size of the coal fragments and the rate of gas escape is strikingly shown by comparing the curves obtained from the crushed coals with those representing the same coals in lumps. Curves 1 and 2 were parallel experiments with the same coal, as were also curves 3 and 4. The finely crushed coals gave out methane at a very rapid rate for a short time after being bottled, but the rate soon rapidly declined. In the experiments represented by curves 7 and 8 the escape was exceedingly rapid during the first week after the crushing, but had greatly slackened before the end of the second week. Bottles 2 and 4 were not opened until the end of the sixth week, so that these two curves are not so sharply bent.

It is clear from these experiments that the gas escapes more readily, and at first in greater volume, from the fine coal than from the coarser lumps, but that the supply of free gas held by the fine coal is more quickly depleted, while the loss from the lump coal is more uniform. After a time, therefore, the coarse coal gives off gas more rapidly than the fine. The graph shows that the curves for the same sample of coal approach each other and will apparently come together in time, probably at a point where the gas supply of each has been practically exhausted. It seems probable, therefore, that the size of the coal, whether finely divided or in the form of coarse lumps, has little influence on the total amount of methane evolved in a sufficiently long period of time, but that it makes a very great difference in the rate at which the gas is given off. The phenomenon appears to be chiefly one involving the quantity of gas stored within the coal which can escape, and not one of gas generation during the interval of time.

Some of the results of these experiments on the rate of escape of gas from Monongah coal may be summed up in the following generalizations:

1. Reduction of pressure removes the gases from coal slowly—a matter of weeks and months.

2. Finely powdered, fresh coal gives off more methane during six months in a vacuum than the same amount of lump coal subjected to the same conditions. But presumably during a much longer period of time approximately the same volume of gas should be expected to come off from either type of coal.

3. Reduction of pressure, acting for only a few hours or even a few days, is far less effective in extracting the entrapped gas than crushing the coal, either in a vacuum or under barometric pressure.

4. Crushing coal to a certain degree of fineness yields approximately the same volume of methane whether the operation is performed in a vacuum or in an atmosphere of air or carbon dioxide.

5. Crushing the coal to the degree of fineness of which the crusher is capable removes only a minor proportion of the free gas stored within the coal. For Monongah coal already crushed, either in vacuum or under full atmospheric pressure, will yield more methane during the next two weeks in a vacuum than was liberated during the process of crushing.

PRACTICAL SIGNIFICANCE OF RATE.

The escape of methane, which takes place slowly and steadily, even from small lump coal, and at a rate that is much influenced by the size of the coal, must continue very steadily for long periods of time from the solid coal in the mines. This means that throughout every portion of a mine, in the old workings as well as the new (except in the portion of the seam near the surface from which the gas has been slowly escaping during long geologic ages), a steady outbreathing of methane gas is to be expected. This may be independent of recognizable "feeders" and "blowers" and may come from the massive coal, as well as from distinct cracks and fissures leading back to storage reservoirs. But because this gas escapes as slowly as it does steadily, it does not often become dangerous in mines where the ventilation is good; but old, abandoned workings, cut off from the rest of the mine and from the ventilation, soon fill with methane from this continual exhalation of gas.

A much greater danger lies in those more rapid outbursts of fire damp which unexpectedly flow into the new workings when a strong blower or reservoir of gas is encountered. Necessarily the quantity of gas suddenly forced into the workings must vary within extremely wide limits, depending on the nature and extent of what may, for convenience, be termed the storage reservoir. These so-called reservoirs of gas are, in reality, porous portions of the coal seam or adjacent strata, or a series of fissures, in which the gas has accumulated and is now stored, at many places under very great pressure. When a crack or fissure leading back to a region of stored gas is encountered in mining operations, an outflow of gas into the workings results. Sudden falls of rock from the roof often open avenues of escape for pent-up gas. When lines of communication with extensive reservoirs of stored gas are opened, large quantities of fire damp may flow into a portion of the mine in a short time and thus render the air in this part of the mine explosive. These lines of communication may be

opened either in the ordinary mining operations or because of the formation of new lines of fracture accompanying the natural deformative movements of the strata. Settling of the overhead beds, together with a general redistribution of the strains caused by the removal of the coal, is likely to open new sets of fissures and seal old ones. Hence there may be periods of more gas and periods of less gas, depending on the local movements of the strata and the effect of such movements, by opening or closing fissures, on the facility with which the pent-up gases can find lines of egress. No appeal, however, is here made to seismic or volcanic disturbances in other parts of the world, whose influence on the local conditions must be trivial.

From these experiments it has seemed safe to conclude that the solid coal in the seam must continue to supply methane for long periods of time. This means that as the supply of gas collected in reservoirs is reduced by escape into the mine, the adjacent coal has a tendency to yield gas to replace that which is lost, until (in case the avenue of escape is cut off by movements of the strata or other causes) a state of approximate equilibrium is established between the gas distributed throughout the mass of the coal itself and that accumulating in the so-called reservoirs. If a reservoir of gas were tapped by boring and the gas removed, the reservoir would, in the course of time, be likely to become recharged, partly at least, with more gas supplied by the adjacent coal, provided the avenue of escape became closed. Just how rapidly a depleted reservoir might be resupplied with gas, and what bearing this factor has on practical mining, must be left an open question for the present.

EFFECT OF BAROMETRIC CHANGES.

When the lumps of coal were placed in the vacuum bottles and the air was exhausted by means of the mercury pump, it was found that the reduction of the pressure to a fraction of a millimeter caused the immediate escape of only a small quantity of methane. The exhaust air from the bottles of Monongah coal contained methane in volumes ranging up to 0.002 of the volume of the coal. Lumps of coal from the Naomi mine and the Mansfield mine at Carnegie, Pa., added similarly small volumes of methane to the exhaust air. Three samples of coal from the mine at Cardiff, Ill., gave only traces of methane, but a fourth, from a gassy portion of the mine, gave off 0.003 of its volume of methane. A bottle of anthracite coal from No. 1 north shaft of the Susquehanna Coal Company, at Nanticoke, Pa., gave off methane to the extent of 0.03 of the volume of the coal while the air was being pumped out of the bottle. The time required to remove the air from these bottles was about twenty minutes. Thus a sudden drop of 740 to 750 millimeters in pressure within twenty minutes does not bring out a very large volume of gas. Experiments already described have shown that time is required to bring out the gas, even in a vacuum.

To discover how much more gas is given off from coal under low pressure than under the full barometric pressure, 20 pieces of bituminous coal from the Mansfield mine at Carnegie, Pa., were placed in a vacuum bottle and the air exhausted. At the same time 21 chunks of similar size, taken from the same collecting can, were placed in a bottle filled with air. The two bottles were then submerged side by side in a water jar. At the end of ten days the gas which had accumulated in the interval was pumped out and analyzed. The coal which had been bottled in a vacuum was found to have given up 0.25 of its volume of methane, while methane amounting to 0.14 of the volume of the coal had accumulated in the bottle that had been filled with air. A similar experiment with two bottles of anthracite coal from Nanticoke, Pa., showed, after an interval of one week, exactly the same relative volume of methane in each bottle—1.07 times the volume of the coal. As in each experiment the volume of methane liberated was greater than the volume of oxygen which the coal absorbed from the air, the final pressure in the air-filled bottles was greater than the barometric pressure.

Low pressure aided the escape of gas from the bituminous coal, but it appears to have had little influence on the liberation of gas from this sample of anthracite coal. That identical volumes of methane should have escaped from the anthracite coal under such widely different pressures is perhaps to be regarded as largely a coincidence, for the distribution of gas is not uniform throughout the coal; but with about 20 fragments of the coal in each bottle, the gas content of the coal in one bottle should not differ greatly from that in the other. It is to be noted that, while the total pressure in each of these air experiments was very different from that in the parallel vacuum experiment, the partial pressure due to methane alone started at zero in each bottle and at the conclusion of the experiment with the anthracite coal had become as great in one bottle as in the other. In considering the influence of barometric fluctuations on the volume of gas exhaled by the coal in the mines, however, it is the total gas pressure which is of significance, rather than the partial pressure due to methane.

It would seem therefore that even the greatest fluctuations of the barometer, which do not exceed 40 millimeters, can not have very great influence on the volume of gas escaping from the interstices of the coal itself. But in the case of feeders and blowers, in which the gas escapes for the most part directly from accumulations stored within more or less connected systems of fissures and zones of fracture, instead of from minute pores in the coal, the effect of the diminution of pressure probably is more marked. This should be particularly true wherever the stored gas is under only a moderate pressure and the pathway of escape into the mine workings is readily followed;

the strong blowers coming from the reservoirs far back in the coal, where the gas is held under high pressure and communication with the coal surface is more difficult, are necessarily much less affected by the relatively slight barometric changes.

Heise and Herbst bring out the point that, although frequent measurements have shown that the gas stored up in the fresh, undisturbed coal often is under pressure amounting to several atmospheres, these high pressures are obtained only by boring several meters back into the coal; and that close to the coal face the gas is under a pressure but slightly in excess of the barometric pressure.[a] Blower gas, in that portion of its course which is near the orifice, is under only a slight pressure, so that an increase in the barometric pressure adds resistance to its outflow, causing it to slacken, whereas with a falling barometer the outflow of gas must become more active. In this way the common observation that the outflow of gas from blowers increases with a falling barometer and slackens perceptibly with a rising barometer is shown to be entirely consistent with the high gas pressures that have been found to exist in the undisturbed coal some distance from the exposed face.

The influence of barometric changes on the outflow of air and gas into the active workings from old abandoned entries which are not completely walled off from the rest of the mine is well known and does not fall within the scope of this discussion.

GASES OBTAINED BY HEATING COAL.

Meyer,[b] Thomas,[c] Bedson,[d] Trobridge,[e] and other investigators have extracted gases from coal with the aid of heat, by warming the coal generally up to the boiling point of water, and in some experiments as high as 200° C. In many tests the higher members of the paraffin series, such as ethane, propane, and butane, were obtained in considerable proportions. At least one gas of the olefin series was often present in notable quantities.

The present analyses of feeder gas from the mines and of the gas which slowly escaped from the coal bottled in a vacuum, as well as of that liberated directly by crushing the coal in the rock crusher, do not reveal the presence of any such high proportions of the heavier hydrocarbons. But these gases were all extracted at ordinary temperatures. As the constituents of coal include various hydrocarbon compounds, some of which may be supposed to be partly decomposed or volatilized at even moderate temperature, there comes to mind

[a] Heise and Herbst, Bergbaukunde, vol. 1, 1908, pp. 458–461.

[b] Von Meyer, Ernst, Jour. Chem. Soc., vol. 25, 1872, pp. 798–801.

[c] Thomas, J. W., Jour. Chem. Soc., vol. 28, 1875, pp. 793–822, and vol. 30, 1876, pp. 144–152.

[d] Bedson, P. Phillips, and McConnell, W., Trans. Fed. Inst. Min. Eng., vol. 3, 1892, pp. 307–310; vol. 7, 1894, pp. 27–53.

[e] Trobridge, F. G., Jour. Soc. Chem. Ind., vol. 25, 1906, p. 1129.

the suggestion that a portion of the olefins and higher paraffin gases obtained from these European coals, instead of existing within the coal in the free state, may have been produced from chemical decomposition induced by the heat employed. To test this possibility, parallel experiments were undertaken. A can of fresh bituminous coal from the Pittsburg district being selected for this test, one portion of the coal was stored for thirty days in a vacuum bottle; a second portion was pulverized on an anvil so as to pass through a 10-mesh screen, and then quickly placed in a suitable glass tube connected with the mercury pump, and the air removed. This tube was then kept for three hours successively at 50° (water bath), 100° (boiling water), 150° (oil bath), and 200° (metal bath). The gas obtained during three hours at each temperature was collected and analyzed. The same experiment was then repeated with anthracite coal from the vicinity of Scranton, Pa. The results, expressed in volume of each gas relative to the volume of the coal as unity, are given in the following tables:

Analyses of gases obtained from coal in a vacuum at different temperatures.

BITUMINOUS COAL.[a]

Gas.	With exhaust air.	At 50°.	At 100°.	Standing over night.	At 150°.	At 200°.	Total.
Hydrocarbon vapors	.....	.....	.....	.....	0.02	0.04	0.06
Carbon dioxide	0.02	0.08	0.06	0.01	.03	.01	.21
Carbon monoxide	.....	.01	.....	.....	.01	.....	.02
Olefins	.....	.01	.....	.....	.....	.....	.01
Ethane	.....	.....	.01	.....	.02	.03	.06
Methane	.07	.58	.63	.11	.70	.17	2.26
Air {Oxygen	.....	.17	.03	.....	.17	.07	1.74
Air {Nitrogen	.....	.67			.63		
Nitrogen (excess)	.....	.06	.14	.....	.02	.06	.28
	.....	1.98	.87	.....	1.60	.38	4.64

[a] 32.56 grams of 10-mesh coal taken from the face of room 21 on No. 4 southeast butt, off No. 6 face entry, in the Mansfield mine at Carnegie, Pa.

ANTHRACITE COAL.[a]

Gas.	With exhaust air.	At 50°.	At 100°.	Standing over night.	At 150°.	At 200°.	At 300°.	Total.
Hydrocarbon vapors	.....	.....	0.02	.....	0.02	0.02	0.03	0.09
Carbon dioxide	0.01	0.18	.15	.....	.02	.02	.01	.39
Carbon monoxide	.....	.01	.01	.....	.01	.....	.01	.04
Olefins	.....	.01	.....	.....	.....	.....	.....	.01
Ethane	.....	.....	.01	.....	.01	.01	.....	.03
Methane	.18	1.06	.99	0.20	.52	.22	.08	3.25
Air {Oxygen	.....	.08	.01	.03	.03	.02	.02	.53
Air {Nitrogen	.....	.30	.04					
Nitrogen (excess)	.....	.39	.12	.02	.....	.....	.....	.53
	.....	2.09	1.35	.25	.61	.29	.15	4.87

[a] 32.33 grams of 10-mesh anthracite coal taken from the E gangway, Babylon vein, in No. 6 colliery at Inkerman, Pa.

The other portions of these two coals were kept in vacuum bottles at low pressures for thirty days. At intervals during this period the gas which had accumulated was pumped out and analyzed, in order to furnish additional data on the rate of methane liberation (see pp. 33–36). The gas was pumped from the bottle containing the bituminous coal at the end of each ten days; from the anthracite at the end of each week, except that the fourth period was extended to nine days to complete the full thirty days.

Of the different portions of the gas analyzed, the last portion in each test furnishes the truest index to the character of the gas given off by the coal when allowed to stand under reduced pressure, as after the removal of several portions of gas the extraneous nitrogen resulting from air still adhering to the coal when bottled, has been largely removed. The gas was still coming off rapidly at the end of the thirty days.

The following table indicates the character of the last portion of the gas obtained from these two vacuum bottles:

Analyses of gases given off by coal during last 10 of 30 days in a vacuum.

Gas.	Bituminous coal.		Anthracite coal.	
	Per cent.	Relative volume.	Per cent.	Relative volume.
Carbon dioxide	12.34	0.01	.....	.....
Carbon monoxide	.22	.....	.....	.....
Olefins	.....	.....	0.29	.....
Ethane	1.90	.....	.....	.....
Methane	80.64	.10	98.58	0.80
Air {Oxygen	.58	.....	.07	.....
Air {Nitrogen	2.19	.....	.26	.....
Nitrogen (excess)	2.13	.....	.80	.01
	100.00	.11	100.00	.81

Ethane was present in the gas from the anthracite coal, if at all, only in small quantities. In two of the four analyses made of the gas from this coal the result of the explosion determinations indicated a small amount of hydrogen instead of higher paraffins. The explosions in the other two analyses pointed to the presence of a small proportion of ethane accompanying the methane.

A comparison of the three tables shows that for these two coals the gas extracted by heating the material up to 200° C. is somewhat, though not radically, different from that which slowly exudes from the coal when bottled for a period at ordinary temperatures. The heat caused the expulsion of such uncombined gas as was ready to escape at ordinary temperatures, and in addition developed some new gas from the nongaseous constituents of the coal. Most conspicuous among these new products were the vapors of hydrocarbons which at

ordinary temperatures are normally liquids. Benzene was probably the most prominent of these vapors. The hydrocarbon vapors began to appear in notable quantities at 100° and increased in importance as the temperature was elevated. The volume of ethane also rose slowly with the increase of heat, suggesting that some of this gas did not come from a state of mechanical imprisonment in the pores of the coal, but was produced by chemical action induced by the heat. Gases of the ethylene series remained unimportant, even up to 300°, in the experiments with the anthracite coal.

The high proportions of higher hydrocarbon gases obtained by Meyer, Thomas, and Bedson by heating German and English coals up to 200° were not found in the gas from these two samples of Pennsylvania coal. By heating dust from the Darr mine up to 350°, however, both olefins and higher paraffins, which at lower temperatures had appeared only in moderate quantities, were made important constituents of the gas evolved. (See tables on pp. 57–58.) Such gases could have come only from chemical action or from a state of true occlusion, for they must inevitably have been liberated in considerable volume at the lower temperatures as well had their liberation been merely a question of escape from the interstices of the coal. Substantiating this view in a measure is the testimony afforded by the vacuum bottles. These experiments show, at least as regards the coals used in these investigations, that the gas slowly coming off from the crushed coal at the end of a period of six months at very low pressures is not notably richer in the higher members of the marsh-gas series than the gas rapidly exhaled at the beginning of the experiments. These higher hydrocarbons do not diffuse and transpire so rapidly as methane, but if they were present in any considerable volume, mechanically held within the pores of the coal, as is the methane, a period of six months would seem sufficient to permit their escape in notable proportions.

STUDIES ON COAL DUST.

EVIDENCE THAT DUST TOOK PART IN EXPLOSIONS.

The analyses of the atmosphere in the return air ways of these exploded mines were made from samples collected five to sixteen days after the explosions. The systems of ventilation were not yet in good repair and were less effective than usual. The after damp had been largely removed, as the analyses discussed under that head show. The accumulation of methane, however, because only a partial restoration of the ventilation had been effected, was probably greater, per volume of air, than was usual when the ventilating systems were in regular working order. This was certainly so in some places. Yet the analyses, most of which were collected so as to get the maximum

of methane, show that the average percentage of this gas throughout the workings of each of the mines was far below the least proportion required to render the atmosphere explosive. Except in samples 17 and 18, collected on different days at the same point in the Darr mine, the analyses of air from the return air currents, away from the coal face, showed less than 1 per cent of methane. Throughout the intake air passages there should have been still less explosive gas. Methane in notable proportions was found only in very local accumulations, either at the coal face or along the roof extending for a short distance from the face. As already remarked, the gas samples, except the specimens of return air, were collected with a view to obtaining the maximum percentage of methane. The figures in the table on page 29 may therefore be taken as expressing the most gaseous conditions which could be found, even locally, in the mines.

Only very local explosions near the coal face could result from such accumulations of fire damp, if this fire damp were the sole explosive agent. In the Monongah mines it was only at a few selected spots that a gas cap could be detected in a Wolf lamp. The main return air currents contained less than half of 1 per cent of methane. Under the conditions of ordinary atmospheric pressure a mixture of air and gas containing less than 5.5 per cent of methane is rarely explosive. In view of this fact it is difficult to see how a general explosion, completely traversing both the Monongah mines, could be possible from gas alone. Compression resulting from a local gas explosion may be supposed to render explosive adjoining air containing somewhat less than 5.5 per cent of methane, but this explanation does not seem adequate.

The other agent present in these mines in large quantities which may, under the proper conditions, become explosive was the coal dust. On entering these wrecked mines after the explosions this potentially explosive material was everywhere to be seen. A thick coating of fine coal dust was found to have settled upon practically everything on which it could lodge throughout the mines. Because of this coating the normally shiny coal of the ribs and faces had become of a uniform dull-black color. In the Darr mine in particular the dull-black dust-covered ribs of the entries in the exploded portion of the mine afforded a striking contrast to the clean, shiny coal in the portion of the workings to which the explosion had not penetrated, possibly owing to the increasing wetness of the entries in that direction. An enormous quantity of coal dust stirred up by an explosion, however originating, is thought, because of the large volumes of inflammable gas which can be rapidly distilled from it at temperatures above 300° C., to have added fuel to the explosion and to have played a very important part in the propagation and extension of the flame throughout the entries where there was little fire damp.

CHARACTER OF DUST DEPOSITS.

The dust deposits observed in the exploded sections of these mines were of several kinds. First, there was the nearly universal coating of dust which had settled upon ribs, timbers, and pavements, inby and outby sides alike, and which was clearly the result of the quiet settling of the floating dust after the disturbing force of the explosion had passed. As this dust settled upon the coal after the explosion, and hence independently of the direction of the blast, it throws no light on the course which the explosion took.

Dust accumulations of another type were those deposited during the passage of the explosion and to a certain extent determined by the force of the blast. Their location thus afforded valuable evidence as to the direction in which the explosion traveled. They were of two sorts, which may be designated "uncharred dust" and "charred dust."

The uncharred dust consisted of a mixture of coal dust, fine slack coal, and finely divided shale, which had been driven into protected corners and plastered against timbers, props, and other obstructions by the advancing explosion. These deposits were most frequently observed on the exposures facing the oncoming explosion, but here and there they were found on both the stoss and lee sides of an obstruction. On some of the exposures facing the explosion the dust was found to have aggregated in the form of a sharp arête, or ridgelike deposit, to each side of which the air blast must have been deflected. Many deposits of this variety of dust approached an inch in thickness. On the other hand, they graded almost imperceptibly into the universal coating of after-explosion dust described above, which they closely resembled in general constitution.

"Charred dust" has been found a convenient term to apply to those deposits of dust which have been partly coked or charred by the heat of the explosion. They differ essentially from the uncharred dust in having lost, by distillation, a portion of their volatile hydrocarbons and in having become coked while in the heated plastic condition. At some points in the mines, where the distillation appeared to have progressed further than usual, there were to be seen on the surface of the charred dust tiny lustrous, silver-like globules, which represented the highest degree of coking observed in the mines. In general, the deposits of charred dust were found as isolated patches in sheltered nooks in the lee of projecting ledges of coal where the force of the explosion was least felt. However, many of the ribs, particularly in room necks or within the rooms, were extensively plastered with charred dust. In several such places in the Darr mine slabs of charred dust a foot square and half an inch or more in thickness could be peeled from the coal rib.

Although the presence of charred dust in various parts of an exploded mine is important as showing the presence of the explosion flame in those parts, the exact location and position of the dust are of much greater significance, as they indicate the direction in which the flame traveled. According to the researches of Sir William Galloway,[a] conducted with the aid of a gallery in which mixtures of fire damp, air, and coal dust were exploded, the "crusts of coked dust were found on the shelves farthest removed from the explosion chamber." Observations in exploded mines made by various authorities have generally agreed that the deposits of charred dust are located chiefly on exposures facing away from the source of the explosion. The distribution of the charred dust in the Monongah and Darr mines was, for the most part, in accord with this view. However, there were many exceptions to this rule. These were most conspicuous at points where the relatively slight mechanical effects of the explosion suggested that the force of the blast was reduced. The deposits of coked dust which faced the source of the explosion were generally small, scattered patches, which had the appearance of having been plastered into cracks directly by the on-coming flame rather than deposited by eddying currents in the lee of projecting ledges.

DUST SAMPLES.

A splendid opportunity to make a comparative study of charred and uncharred dusts was afforded by the conditions in room 3 on No. 3 right entry off No. 2 north heading, in mine No. 8 at Monongah. In this room the deposits of both varieties of dust were unusually heavy, particularly upon the props. The outby sides of these timbers (facing the entry) were thickly covered with dust which showed no indication of charring or other visible evidence of having passed through an explosion. The inby sides of the same props were completely plastered with well-charred dust. The opposite sides of these timbers presented a very striking contrast. Specimens of these different dusts, which were so admirably separated by the mechanics of the explosion, were collected by spreading a piece of canvas on the ground and then scraping down the dust, first from one side and then from the other. The charred dust from the inby exposures fell in cakes, while the dry, uncharred dust showed the general consistency of flour. At the same time that separate coal-collecting cans were filled with charred and uncharred dust from props about 45 feet from the mouth of the room, a third can was filled with fresh coal dug from the rib at a point about 30 feet from the room mouth.

[a] Proc. Roy. Soc. London, vol. 33, 1882, pp. 437–445, 490–495.

Analysis of this material gave the following figures:

Analyses of dust samples, compared with fresh coal from same locality.[a]

	Moisture.	Volatile matter.	Fixed carbon.	Ash.
Fresh coal from rib	1.24	35.28	59.88	3.60
Uncharred dust, 1	2.30	24.13	45.01	28.56
Uncharred dust, 2	2.34	23.43	45.19	29.04
Charred dust, 1	1.13	24.78	58.11	15.98
Charred dust, 2	1.20	24.36	59.33	15.11

[a] The method of analysis was the official method recommended by the coal-analysis committee of the American Chemical Society, except for the determination of volatile matter, where the modified method, described in Bull. U. S. Geol. Survey No. 323, pp. 36-39, was substituted.

The two analyses of each of the dusts are not duplicate analyses of the average dust, obtained by the usual quartering process, but were made from distinct samples taken from opposite ends of the cans, in order to show how much variation there might be in the composition of each dust. But some mixing of the flourlike, uncharred dust must have taken place during the transportation of the can from the mine to the laboratory.

The most striking feature of these comparative analyses is the high proportion of ash in the dusts compared to that in the original coal. This high ash was due to an admixture of shale, numerous small particles of which were recognizable in the ash residue after the fixed carbon had been burnt out of the dusts. This shale had been derived from the strata of the roof and floor, partly through the force of the explosion and partly from the previous mining operations. The uncharred dust contained nearly twice as much ash (shale) as the charred dust. This is significant, for if the two dusts contained the same proportion of admixed shale when the flame reached them the loss of a considerable portion of the volatile hydrocarbon matter from the coked dust would correspondingly raise the percentage of ash and shale in that dust. Hence, without some conflicting agency, the charred dust should be characterized by a higher percentage of ash than the corresponding uncharred dust.

EXPLANATIONS OF DUST EFFECTS.

Mine timbers, heavily plastered on one side with charred and coked dust containing 15 per cent of ash and shale, while the opposite faces were covered with a thick deposit of uncharred dust carrying nearly 30 per cent of mineral waste, may well give a valuable clue to some vital factor in the explosion. The explosive process resulted in two very striking differences in dusts deposited only a few inches apart, but in different situations. If we seek the relation between the charring action of the flame and the percentage of shale, it is clear that the difference in the proportion of shale and ash can not

be the result of the coking process, for this process can only increase the difference. The reverse alternative, that the difference in charring has come as a direct result of the difference in the shale content of the two dusts, seems more promising. It is a well-recognized fact that the presence of a noncombustible substance, intimately mixed in any considerable proportion with combustible matter, renders that matter less inflammable than it is in the pure state; and that if sufficient noncombustible matter is added the mixture will become incapable of sustaining combustion by itself. It may be that this principle has been operative here. The explosion flame was able to burn with sufficient vigor to coke the dust with which only 15 per cent of shale was mixed, but where the shale impurity amounted to 28 to 30 per cent of the total, the flame seems to have failed to reach the intensity necessary to coke the dust.

The explanation of the difference in the quantity of fine shale on the opposite sides of the timbers is perhaps to be found in the marked difference in the specific gravity of the coal and the shale. The sample of coal from this room had a specific gravity of 1.273. No specimen of this Monongah shale was collected, but an average shale of this sort would have a specific gravity of about 2.6, or twice that of the coal. So great a difference should have a marked influence on the facility with which such dusts are transported by air blasts, and also on the conditions under which they will be deposited.

In room 3 on third right entry off the second north heading the uncharred dust, characterized by the high shale content, was on the outby sides of the props, while the coked dust with less shale impurity, coated the inby surface of these props. The explosion did not originate in this room, but advanced into it from the entry, and hence its blast was directed against the outby facing exposures. The storm of coal and shale dust being driven against the outby sides of the props, portions of both dusts lodged there; but it is probable that there was collected on these exposures a relatively larger proportion of the shale, which, owing to its greater density, was driven straighter and with more force against the props, while relatively more of the lighter coal dust was swept around the props by the eddying currents. As the blast passed around each prop and an eddying current was formed in the lee of the prop, the lighter coal-dust particles would be most easily deflected from their previous courses and most abundantly plastered on the lee side by the eddy, while the heavier particles of shale, because of their greater momentum, would tend to continue in less deflected lines beyond the influence of the prop. It follows that on the inby or lee side of the timbers there would be proportionately more coal dust and proportionately less shale dust than on the outby exposures.

An alternative though not radically different hypothesis to account for the deposition of the purer coal dust on the inby faces may be entertained. In this no appeal is made to eddying currents sweeping around the timbers and sifting out and depositing relatively more of the coal dust than of the shale dust on the lee sides. The storm of dust is supposed to have continued past the timbers to the face of the room, where the force of the blast was cushioned and many of the heavier particles of shale were dropped. The weaker return wave produced by the reaction might then bring back a relatively larger proportion of the lighter coal dust, which would be deposited directly against the inby exposure of the timbers.

The high proportion of shale in the dust which was being driven against the outby sides of the props, by diluting the combustible coal dust and at the same time absorbing much of the heat produced by the flame, without itself contributing fuel to the explosion, may have had such a damping effect on the flame that the dust was not charred. But in the lee of each prop, where, in the eddying current, the proportion of shale had become much reduced, the flame was able to burn with greater vigor, and the dust became partly coked. Or, if we follow the alternative hypothesis, the coking process took place while the coal dust, purified by leaving much of the shale near the face of the room, was being carried back to the props by the weaker return wave. This view possesses certain possible advantages over the other, in that more time is allowed for the coking of the purified coal dust while traveling back from the coal face, and also because with it may be postulated great compression as the blast drove against the coal face, attended by sudden liberation of heat, which in turn facilitated the coking of the suspended coal dust returning toward the props.

CAUSE AND MANNER OF COKING.

The question naturally arises, to what extent may the coking of the dust be due to the charring effect of the flame after the dust has been deposited, and to what extent was the dust already coked when it was plastered against the obstacles where it lodged. This includes the allied question whether typical charred dust can be formed by a return flame, or sweep of hot gases, coming back along the path of the explosive blast and coking a deposit of the dust which, up to that time, had not been charred. To determine the coking effect of a flame upon aggregated coal dust, fresh coal from the face of room 1 on No. 33 heading, Naomi mine, was finely powdered and a dome-shaped pile of it, half an inch in height, subjected to the full flame of a Bunsen burner for thirty seconds. A thin, fragile disk of charred dust, less than an eighth of an inch in thickness, was the result. This small disk, about the size of a dime, was so poorly consolidated

that it could scarcely be handled without falling to pieces. Below this thin covering the dust was not visibly affected by the heat of the flame.

In the mines, on the other hand, charred dust was found in favorable places in layers an inch in thickness and so tenacious that slabs a foot square could be stripped off. Such slabs usually showed rather uniform coking throughout, and uncharred dust was not found beneath the cakes.

This uniformity of coking naturally favors the conclusion that the dust was coked while in the air and deposited in the semiplastic condition. The force of impact, which may be supposed to have packed the dust, may account for the greater tenacity with which it holds together. These conclusions are greatly strengthened by the laboratory experiment, which shows that a Bunsen flame, impinging upon fresh coal dust for thirty seconds, produces only a superficial layer of char, much less consolidated than the charred dust in the mines. The dust in the mines could have been exposed to the flame and hot gases for only a fraction of this length of time, as the small splinters of wood on the mine timbers generally were not charred, though locally evidence of some burning was found. Hence the coking of the typical charred dust had probably already taken place, for the most part, before it was deposited.

LOSS OF VOLATILE MATTER.

The coking process consists chiefly in the distillation and expulsion of a portion of the volatile hydrocarbons, which add fuel to the flame. In order to obtain an idea of how much volatile matter was lost in the explosion we may take the comparative figures for these dusts, whose true import is obscured by the admixture of so much shale, and reduce them to a common, shale-free basis. Assuming that the original coal containing 3.60 per cent of ash, and reducing the ash content of both dusts to this proportion, we obtain the figures below:

Analyses of dust samples recalculated on basis of equal proportion of ash.

	Moisture.	Volatile matter.	Fixed carbon.	Ash.
Fresh coal	1.24	35.28	59.88	3.60
Uncharred dust, 1	3.09	32.57	60.74	3.60
Uncharred dust, 2	3.18	31.83	61.39	3.60
Charred dust, 1	1.29	28.43	66.68	3.60
Charred dust, 2	1.35	27.67	67.38	3.60

The figures for the charred dusts calculated in this way are not strictly correct, as no account is taken of the fact that, because of the loss of a portion of the volatile matter, the percentage of ash, instead of remaining at 3.60, should be increased proportionally, but the difference is not great and causes no error of importance.

The two analyses of uncharred dust show a loss of 2.71 and 3.45 per cent of volatile matter, compared with the fresh coal. A portion of this difference is thought to be due to the fact that the material used in the analysis of the fresh coal was passed through a 10-mesh sieve, but was too coarse to pass through a 30-mesh sieve, whereas the uncharred dust was much finer than this. N. W. Lord[a] has brought out the fact that, with the modified method of analysis, the determination of volatile matter will appear about 1 per cent lower for very finely powdered coal (80-mesh and finer) than for coarser coal (20 to 40-mesh). Allowance is to be made for this difference, and a later determination made with very finely powdered material gave 33.44 per cent of volatile matter in this sample of coal. Strangely, the loss of volatile matter has been approximately compensated by a gain in the moisture, perhaps due to the shale, so that the percentage of fixed carbon has not been greatly changed.

Compared with the original analysis of the fresh coal, the analyses of the charred dust indicate a loss of 6.85 and 7.61 per cent of volatile matter and but little change in the moisture content. The charred dust, according to these figures, has lost more than twice as much volatile matter as the uncharred. But as the variability of the moisture content has some influence on these figures, it may be well to give the ratios between the fixed carbon and the volatile matter. This ratio for the fresh coal is 1.69 to 1; for the uncharred dust, 1.86 and 1.93 to 1; and for the charred dust, 2.34 and 2.44 to 1. Although it is possible that a small amount of fixed carbon has been consumed, along with the volatile combustible hydrocarbons which the charred dust has fed to the explosion flame, this would seem relatively unimportant, for experiments show that, although coal dust when heated to redness yields up its volatile matter readily and rapidly, considerable time is required to burn out the fixed carbon that remains after the escape of these more volatile products. Thus, when only a part of the volatile matter has been removed from the dust samples obtained in the mines, it is not likely that much of the so-called fixed carbon has been consumed, at least from these particular samples.

Analyses of the gas evolved from coal dust at temperatures up to 450° C. show that these combustible products comprise the vapor of benzene and associated hydrocarbons, ethylene and its homologues, methane and the higher paraffins, and carbon monoxide, together with a little hydrogen sulphide. (See tables on pp. 57–58.) At the same time certain noninflammable gases, such as nitrogen, carbon dioxide, and sulphur dioxide, are produced in more or less subordinate proportions. The combustible gases are evolved in large volumes and some of the molecules of the higher hydrocarbons, be-

[a] Experimental work conducted in the chemical laboratory of the fuel-testing plant at St. Louis: Bul. U. S. Geol. Survey No. 323, 1907, p. 40.

cause of their complexity, require large proportions of oxygen. It is therefore to be expected that, in many cases, these inflammable compounds will not find sufficient oxygen for their complete combustion. The need of more oxygen is doubtless one of the reasons why dust explosions seek the fresh intake air in preference to the less oxygenated return currents. At Monongah mine No. 8 the destruction at the pit mouth was very great.

COMPARISON OF OTHER DUST SAMPLES.

These samples of charred and uncharred dust from a room in Monongah mine No. 8, which were so admirably separated by the explosion itself, were the best samples available to furnish data on the mechanics of the explosion. Other cans were filled with dust from the Naomi and Darr mines, but conflicting factors, whose possible influence can not be determined, make results based on some of them of uncertain value. Analyses of other samples of charred dust do not all reveal the low proportion of shale observed in the dust on the props in room 3 just described. They are given below:

Analyses of additional dust samples.

No.	Material analyzed.	Moisture.	Volatile matter.	Fixed carbon.	Ash.
1	Charred dust	0.88	16.24	45.38	37.50
2	Do	1.25	14.54	52.79	31.42
3	Do	1.14	13.33	70.78	14.75
4	Uncharred dust	6.07	19.51	45.81	28.61
5	Do	2.31	20.46	31.68	45.55
6	Do	1.24	20.84	28.78	49.14

1. Charred dust collected on December 14, 1907, inside the screen (9 meshes of 1 inch each) of the electric headlight on a motor, center main at No. 28 chute, Naomi mine. The headlight of the motor faced the explosion and the dust was driven straight through the screen against the reflector. The high percentage of shale was perhaps a momentum effect.

2. Charred dust collected on January 5, 1908, from the inby end and inby bumpers of a mine car, 25 feet outby No. 1 left butt, on entry 28, in the Darr mine. At the point where this sample was obtained there was some suggestion of a conflict of forces, so that the value of the analysis is uncertain. The car from which this dust was obtained was the last (inby) of a trip of 12 cars. It had been derailed and partly turned sidewise, but those who examined the car differed as to the direction of the force which derailed it. In the ash which resulted from burning this charred dust in a crucible, numerous fragments of shale as large as a cubic millimeter were noticeable. These fragments of shale were both more numerous and larger than those in the ash from the charred dust on the props in the room in mine No. 8 at

Monongah. To determine whether a portion of the shale might have been swept into the already charred mass by a return blast of hot gases coming down the entry, the outer portion of a cake of this dust was cut off and an ash determination was made of the protected portion of the cake. The result was 29.72 per cent of ash in the protected half of the cake, compared with 31.42 per cent ash for the whole.

3. Charred dust collected January 4 from the face of room 1, on No. 8 left butt, off the swamp entry, in the Darr mine. This specimen represented a very extensive and thick deposit plastered against the coal face. As it was at the end of the room, this dust was necessarily blown directly against the face upon which it lodged. Evidence of more than a very moderate mechanical force was lacking at this point, and this was true generally where deposits of charred dust occurred in similar situations facing the source of the explosion. With less force, the explosion wave could gather up and carry along less of the heavier shale. This sample of charred dust contained the lowest percentage of shale impurity, and was at the same time the most thoroughly coked of all the dusts collected.

4. Uncharred dust gathered January 2, from the inby end of an 8-inch pipe 18 feet in length, which was lying along the left rib of the main entry, just opposite entry 21, Darr mine. This dust, which had accumulated in the pipe, contained a much lower proportion of shale than the dust on the floor near by, showing that the coal dust was more easily swept into the pipe than the heavier shale. At the same time, the dust in the pipe was in a position unfavorable to participation in the explosion.

5. Uncharred dust collected January 2 from the pavement along the left rib of the main entry, just opposite entry 21, in the Darr mine. This was 15 feet outby from the iron pipe from which sample 4 was obtained.

6. Uncharred dust from the other end of the can from which sample 5 was taken. This analysis was undertaken to show the amount of variation in the composition of this dust.

RESTRAINING FACTORS—SHALE AND DAMPNESS.

The three samples of uncharred dust were obtained near the point in the Darr mine where the last bit of charred dust was found. Between this point and the mine mouth, a distance of about a mile, no charred dust was seen. Though the explosion continued past this place, the flame left no record of itself, and the work done by the mechanical forces is less and less distinct. Whether the restraining influence of so high a proportion of noncombustible shale, or the reduction of the explosive capacity of the dust by the loss of a portion of its inflammable gas and the partial oxidation incident to its long

exposure to the air, or entirely different conditions, have been the most potent factors in damping the explosion in this main entry must for the present remain largely a matter of conjecture.

In the first two samples of charred dust analyzed, the ash residue was characterized by fragments of shale considerably larger than any found in the dust from the props in the room at Monongah. This is a factor of much importance, for the possible damping effect of a certain proportion of shale is dependent, to a great extent, on its fineness of division. If the total mass of the shale is concentrated in a few large pieces this noncombustible matter can have little influence on an explosion; but the same weight of shale in a finely divided state, and intimately mixed with the coal dust, may have a marked restraining influence on an explosion, and if in sufficient quantity render the coal dust incapable of propagating an explosion.

The chief result of the presence of shale dust is the absorption of so much heat from the flame that the latter can not perpetuate itself. Essentially the same principle underlies the experimental observation of German investigators that, when the walls of an explosion gallery are sprinkled with water, dry dust may be stirred into the air without being set off by the usual charge of dynamite used to explode the particular variety of dust. After a large number of trials with charges of 25 to 300 grams of gelatin dynamite, the most explosive mixtures of fettkohlen dust in a dry condition remained unignited when the walls of the galleries were sprinkled just before the trials. With the gallery walls dry, a charge of 50 to 75 grams of dynamite sufficed to explode this dust.[a] The investigators stated their belief that the effect of such sprinkling was due less to the water rendering the dust nonexplosive, than to restraint of the genesis and propagation of the coal-dust explosions as a result of the rapid cooling of the flame by the wet walls of the gallery.

The effect of the dampness of the walls and floor in limiting the spread of a dust explosion was indicated on entry 21 in the Darr mine. This entry led to an older and lower part of the mine, near the river level, where the workings were continually wet. The explosion, advancing along entry 21 from the main entry, carried a piece of the overcast (located 50 feet from the mouth of the entry) a distance of 220 feet and spread a deposit of fine dust on the ribs to a distance of 600 feet from the main entry. Beyond this point the coal on the ribs of entry 21 was clean and lustrous, and the rib corners and exposed edges were all very angular, in striking contrast to the partly rounded edges which had been polished by the dust blast throughout the exploded portion of the mine. As far as the coating of dust extended along this entry water lay under foot only here and there in pools, but the ribs showed increasing dampness. Farther

[a] Niederrheinisch-Westfälischen Steinkohlenbergbaues, vol. 7, pp. 509-510.

on they became distinctly wet and standing water was abundant. No charred dust was found in this entry. Apparently the explosion flame, which had become enfeebled by the time it reached the mouth of entry 21, as previously mentioned, was completely checked on reaching the wet portion of that entry.

PRACTICAL CONSIDERATIONS AS TO DANGER OF EXPLOSIONS.

INFLUENCE OF SEASONAL CHANGE.

One of the chief lessons learned from the series of disastrous explosions in the bituminous coal mines in December, 1907, was the influence of the first touch of cold weather on the danger of coal-dust explosions. During the summer the air in the mines is cooler, on the average, than the outside air. As a consequence, when the warm air is drawn into the mine, saturated or nearly saturated with moisture, and then cooled, a certain amount of this moisture is condensed and serves to keep the mine damp. But with the approach of cold weather the conditions are reversed. The outdoor temperature becomes much lower than that in the mines. The result is that, whether the cold air going into the mines is saturated with moisture or not, as soon as its temperature rises in passing through the mine its capacity to absorb moisture becomes proportionately increased and it begins to dry out the mine. If the air is only partly saturated when it enters the mine its drying effect will be just so much greater. On January 4 and 5 tests made with a psychrometer by W. O. Snelling, of the United States Geological Survey, showed that the air was entering the Darr mine in a partly saturated condition at 25° to 35° F., but that after the air had passed through long stretches of entry and reached the coal face its temperature had risen to 60° F. and it had absorbed moisture till it contained 95 to 97 per cent of its full capacity at that temperature. This indicated the absorption of much moisture during the passage of the air through the entries. These entries, except No. 21, which led to a lower portion of the mine near the river level, and scattered pools of water elsewhere, were quite dry at the time of the inspection.

Inasmuch as the large volume of air forced through the mines keeps the dust in a dry condition during the winter except for a short time after sprinkling, the danger from dust explosions is greatest during the cold season. The disastrous explosion in the Marianna mine (Pennsylvania), November 28, 1908, and the four terrific explosions in the Naomi, Monongah, Darr, and Yolande (Alabama) mines, all of them coming in December, suggests that the period of greatest danger probably comes early in winter, when, as a result of the change in atmospheric conditions, the mines first become dry. A rapid current of air will dry a mine quicker and more completely

than a slow one. Hence, in so far as dust explosion is favored by dryness of the dust, if sprinkling is the only precautionary measure used, the danger of dust explosion is increased by increase in ventilation. Up to a certain point, the more perfect the ventilation of a mine during the winter, the drier and more dangerous does the dust become. But good ventilation is indispensable to proper mining conditions, and hence any suggestion of means for reducing the dangers incident to strong ventilation without lessening the volume of air passing through the workings should be welcome, even if it only serves to stimulate further investigation.

EFFECT OF SHALE DUST ON EXPLOSIONS.

To this end the suggestions drawn from the foregoing observations in the mines and in the laboratory will be briefly stated, subject to modifications as further investigations and practical experience require. The observations and analyses give rise to a very definite suggestion as to a possible mode of reducing the liability of dusts to explode. This suggestion grows out of the striking difference which the analyses disclose between the charred, the uncharred, and the fresh coal dusts, with regard to the respective percentages of shale in them, particularly as shown on the opposite sides of the props in the Monongah mine. These differences indicate that the proportion of shale present in the dust exerted a marked influence on the degree of coking and the extent to which the dusts participated in the explosions. They suggest that the principle which seems to be involved might be applied to effectually reduce the danger of a general explosion throughout a mine, if not to render one practically impossible.

Among the possible advantages which may be claimed for the use of shale, earth, or lime mixed with water are the adhesiveness of mud and its property of holding together even after it has become completely dry. By adhering to the fine particles of coal, it would form a dust much less readily stirred into the air in every-day mining operations. A coating of mud, clay, shale, or whitewash on the ribs and preps must bind the coal-dust particles to the coal or timbers with sufficient tenacity to prevent this dust from being swept up by the ordinary currents of air passing through the entries. Because of greater adhesiveness mud or soft clayey shale is preferable to the more indurated slates, but whitewash has some properties which make it superior to either.

The property of noncombustible shale to diminish the inflammability of the coal dust is not dependent on the presence of a continuous supply of moisture in the mines. Sprinkling with water alone is effective for a time; but if the dust is once made comparatively harmless by the admixture of a large amount of very fine shale

or similar adhesive mineral matter it remains so (even though the mine be completely dried out) until an additional amount of coal dust has accumulated or the dusts in some way become partly separated.

Whether shale dust on the entry floors alone is competent to check a dust explosion once under way when fine coal dust unmixed with shale or whitewash is present upon the ribs and timbers can be told only by experiment. That an enormous amount of dust and coal in fine particles is swept along the entries during an explosion was clearly brought out by an inspection of the coal ribs in the exploded mines. Very generally throughout these mines, except where the mechanical force of the explosion was greatly reduced, the exposed corners and protuberances of the coal were rounded or even highly polished on exposures facing the source of the explosion, but nearly all the corresponding exposures facing away from the blast were angular and dull. This rounding indicated much abrasion and wear and resembled somewhat the familiar polishing of bowlders and pebbles by the sand blasts in arid regions. As this smoothing of corners and burnishing of exposed surfaces was all accomplished in the very short time which the explosion occupied in traveling through a given section of an entry, the mass of dust and particles of coal carried along by the blast must have been very great. If the floor of an entry should be thickly covered with fine noncombustible shale dust, it is possible that an explosion sweeping up such a mass of material might be checked by that influence alone.

COMPARATIVE INFLAMMABILITY OF OLD AND FRESH COAL DUSTS.

SUPPOSED DANGER IN OLD DUST.

The statement has been made occasionally in mining literature, but apparently without very definite experimental basis, that the old dust along the main haulage ways, which has been long exposed to the action of the air, is more dangerous than the fresh dust close to the working faces. The reason for this belief, it has been stated, lies in the presence of oxygen occluded by the dust during its extended exposure to the air. The presence of a considerable amount of oxygen condensed upon the surface and in the pores of the dust would seem to be favorable to the rapid combustion of the coal dust when the exciting cause of the explosion appears. And as it has long been known that coal absorbs oxygen from the air, it was natural to conclude that weathered coal dust which has absorbed much oxygen must be more inflammable than dust from the same coal which has been exposed but a short time.

TESTS ON DIFFERENTLY EXPOSED SAMPLES.

To throw light on several phases of this question at once, two samples of dust, placed in a vertically held combustion tube connected with the mercury exhaust pump, were heated by slow degrees up to 450° C., and the gas evolved at different stages was pumped off and analyzed. The first of these samples was old, weathered, but unexploded dust gathered from the main haulage way of the Darr mine; the second was a fine powder freshly prepared in the laboratory by pulverizing coal from the same mine. This fresh powder was placed as quickly as possible in the tube, and the air exhausted. In each experiment the exhaust air was collected and analyzed; then the tube was warmed and kept immersed in boiling water for a couple of hours, and the gas evolved was removed for analysis. After that the tube was heated on a metal bath successively to 225°, 350°, and 450° C. and kept at each temperature for several hours, and for each such period a portion of gas was obtained.

By this treatment, it was thought, could be determined not only the relative volume of combustible and noncombustible gas which the two different dusts can produce when heated up to 450°, but also the volume of oxygen which had been occluded by the dusts. At the same time, as the old dust came from an exploded mine, though unexploded itself and taken from a locality where the explosion flame had left very little evidence of its presence, it was thought best to treat, in addition, a sample of old dust which it was certain had never been at all affected by an explosion. For this purpose coal from the Darr mine was reduced to a fine powder in a mortar, spread out thinly upon sheets of paper in a laboratory hood which was not in use, and allowed to remain thus exposed to the air for a period of two months. It was then subjected to exactly the same treatment as the other two dusts.

The results of these three series of tests, expressed in volume of each gas relative to the volume of the dust, are given in the following tables:

Analyses of gases obtained from coal dust of different degrees of exposure.

[Relation to volume of dust as 1.]

OLD DUST LONG EXPOSED TO THE AIR.[a]

Gas.	Exhaust.	3 hours at 100° C.	2½ hours at 225° C.	5 hours at 350° C.	5 hours at 450° C.	Total up to 350° C.
Sulphur dioxide / Hydrogen sulphide	.....	.....	0.01	0.09	0.02	0.10
Carbon dioxide	0.02	0.02	.18	.71	.35	.93
Carbon monoxide	.01	.004	.03	.23	.23	.27
Hydrocarbon vapors	.....	.....	.....	.....	.50	.....
Heavy hydrocarbons	.....	.....	.....	.10	.31	.10
Methane series	.006	.002	.02	.25	1.71	.28
Air (oxygen and nitrogen)	.....	.03	.04	.....	.02	.....
Nitrogen, excess over air	.....	.06	.....	.....	.....	.....
	.036	.12	.28	1.38	3.14	.....

[a] Fine dust from the left rib of the main entry, just opposite entry 21, in the Darr mine.

Analyses of gases obtained from coal dust of different degrees of exposure—Continued.

FRESH DUST.[a]

Gas.	Exhaust.	2 hours at 100° C.	2½ hours at 225° C.	5 hours at 350° C.	1½ hours at 450° C.	Total up to 350° C.
Hydrogen sulphide	.....	.....	.....	0.02	0.27	0.02
Carbon dioxide	0.01	0.03	0.04	.28	.56	.36
Carbon monoxide	.....	.....	.02	.06	.25	.08
Hydrocarbon vapors	.....	.....	.....	.56	.57	.56
Heavy hydrocarbons	.....	.01	.01	.19	1.05	.21
Methane series	.10	.92	.23	1.12	7.19	2.37
Air (oxygen and nitrogen)	.....	.10	.01	.01	.11	.....
Nitrogen, excess over air	.....	.....	.02	.....	.....	.....
	.11	1.16	.33	2.24	10.00	.....

[a] Coal from face of ninth left, off entry 27, Darr mine, very finely pulverized in a mortar and quickly placed in the tube and the air exhausted.

DUST TWO MONTHS OLD.[a]

Gas.	Exhaust.	3 hours at 100° C.	2½ hours at 250° C.	5 hours at 350° C.	4 hours at 450° C.	Total up to 350° C.
Sulphur dioxide } Hydrogen sulphide	.....	.....	.....	.....	0.19	.....
Carbon dioxide	0.02	0.02	0.16	0.59	.85	0.79
Carbon monoxide	.....	.....	.05	.20	.40	.25
Hydrocarbon vapors	.....	.....	.11	.17	1.51	.28
Heavy hydrocarbons	.....	.002	.01	.06		.07
Methane series	.03	.008	.06	.35	4.86	.45
Air: Oxygen	.....	.01	.02	.01	.04	.....
Air: Nitrogen	.....	.04		.04	.15	.....
Nitrogen, excess over air	.....	.02	.....	.....	.....	.....
	.05	.10	.41	1.42	8.00	.....

[a] Coal from the Darr mine, finely pulverized and exposed to the air in the laboratory.

When the fresh dust, in the experiment just tabulated, was heated to 450° C., gas came off so rapidly and was obviously so much the result of chemical decomposition and distillation of the volatile non-gaseous hydrocarbons that the experiment was stopped at the end of one and a half hours, though gas was still coming off steadily. In the experiment with the dust which had been exposed for two months, the operation was stopped at the end of four hours, though gas was still coming off. As at 450° chemical action is strong, and as the temperature was not kept so uniformly at the mark as with the lower temperatures, comparative results are less significant and less trustworthy. Therefore in the total volume for each gas given in the table, only the gas obtained up to 350° has been included.

SIGNIFICANCE OF TESTS.

These three tests gave quite different results, and the variation appears to be highly significant. The old dust and, to a somewhat lesser degree, the dust exposed to the air for two months had lost a large proportion of their free methane and heavy hydrocarbons. Much of this loss was probably due to simple escape from the finely divided coal, as the experiments with bottled coal have shown that gas is con-

tinually escaping from coal and that the escape proceeds at an especially rapid rate, for a short time after pulverization, from fine coal. (See p. 35.) This escape was a distinct loss of the most available explosive constituents. On the other hand, the old, exposed dusts yielded much more of the oxides of carbon and sulphur than the fresh dust. This indicates that simultaneously with the loss of the hydrocarbon gases a process of oxidation had been going on, which had converted a portion of the carbon of the coal into carbon monoxide and carbon dioxide and some of the sulphur into sulphur dioxide. The increase in the volume of carbon dioxide and of carbon monoxide was about the same; and this showed that, while there had been some complete oxidation to the dioxide, there had also occurred some partial oxidation of the coal to compounds readily decomposed by heat with the evolution of carbon monoxide.

Sulphur dioxide was especially noticeable in the gas obtained at 225° and 350° C. from the old, weathered mine dust, though it was not prominent in the gas from the dust exposed in the laboratory. It had probably been derived from the oxidation of the pyrite in the coal to ferrous sulphate or basic ferric sulphate, which was decomposed by the heat employed, with the formation of sulphur dioxide:

$$2FeSO_4 = Fe_2O_3 + SO_2 + SO_3.$$
$$Fe_2S_2O_9 = Fe_2O_3 + 2SO_3.$$

The sulphur trioxide was reduced to the dioxide by oxygen-absorbing compounds in the coal. The dry air of the laboratory evidently was not so favorable to the weathering of the pyrite as the conditions in the mine, for the artificially weathered coal dust yielded more hydrogen sulphide than sulphur dioxide. The sulphur gas from the fresh coal was largely hydrogen sulphide. Where both gases were produced by the same dust, as from the old mine dust, sulphur dioxide was most conspicuous at the lower temperatures; at 450° C. the sulphur gas, even from the mine dust, was largely hydrogen sulphide.

Free oxygen formed only an insignificant portion of the gas obtained in these experiments and was regarded as most probably due to a slight leakage of air during the course of the heating process. In exhausting the air from the tubes, however, there was obtained, for two of the three samples, slightly more oxygen in proportion to the nitrogen than is found in pure air. The ratio of oxygen to nitrogen in pure air is 0.264 to 1. In the last 9.48 cubic centimeters of the exhaust from the tube containing the old dust, the ratio of oxygen to nitrogen was 0.265 to 1; in the last 58.65 cubic centimeters of the exhaust from the coal which had been exposed for two months the proportion was 0.264 to 1; and in the last 16.25 cubic centimeters of air from the freshly powdered coal, the ratio was 0.280 to 1. It is possible that there was a slight increase in the proportion of oxygen

even in the two-months dust, and that this slight increase was obscured by the large volume of air collected. The total volume of oxygen in these last portions of the exhaust air, in terms of the volume of dust as 1, was, for the old dust, 0.11; for the two-months dust, 0.73; and for the fresh dust, 0.14. The excess of oxygen in the exhaust air therefore is quantitatively very insignificant. Moreover, in these tests it was greatest in the fresh dust, which was exposed to the air in all less than half an hour before the air was pumped out of the tube.

That exhaust air from a tube containing coal is slightly richer in oxygen than normal air was first noted by Trobridge,[a] whose work confirmed the observations made by Bedson and other investigators that oxygen and nitrogen, the former preferentially, are absorbed by coal when exposed to the air. That portion of the oxygen absorbed from the air, which is thus readily released from the coal with a relief of pressure, may be regarded as occluded gas held by the coal in the free state. This gas comes off largely on the simple relief of presssure. But the volume of oxygen which comes off on the reduction of pressure is quantitatively only a small fraction of that which has been absorbed. The foregoing tables, confirmed by the results of various other experiments, indicate that after a vacuum has been produced in the tube containing the dust or coal, very little more free oxygen is obtained when the tube is heated. Two hypotheses naturally present themselves. According to one, free oxygen still remains within the coal, but does not come off when heat is applied, because the heat causes it to unite chemically with the coal. The other is that after the absorbed oxygen has been removed by the reduced pressure, very little of the gas remains within the coal in the free state. Though chemical union might be supposed to take place at the higher temperatures, there appears to be much less reason to assume that the union which has not taken place at ordinary temperatures will proceed rapidly at 100° or 200° C. The second hypothesis, that the greater part of the oxygen absorbed has already entered into chemical combination at ordinary temperatures and that little uncombined oxygen remains in the coal, seems the more probable.

ABSORPTION OF OXYGEN BY COAL.

Although comparatively little free oxygen can be extracted from coal, experiments show that very large volumes of oxygen are rapidly and steadily absorbed by coal. It was knowledge of this fact that has suggested belief in the greater inflammability of the long-exposed coal dusts. But this idea is based on the assumption that much of this oxygen remains in the coal in the free state. The experiments with dust (see tables, pp. 57–58) indicate that, with exposure to the action of the air, there is a development of the oxides of carbon and

[a] Trobridge, F. G., Jour. Soc. Chem. Ind., vol. 25, 1906, pp. 1129–1130.

sulphur within this dust, or of compounds which give off these gases at moderate temperatures. Coal bottled with air for a few days gives off a much higher proportion of carbon dioxide than if placed in a vacuum. But it does not give off as carbon dioxide, within a short time at any rate, more than a small percentage of the oxygen absorbed from the air in the bottle. Air bottled with Illinois (Cardiff mine) coal for two weeks contained, at the end of that time, only 1.05 per cent of oxygen and 1.59 per cent of carbon dioxide, together with 0.62 per cent of methane and 96.74 per cent of nitrogen. Thus only a small proportion of the oxygen which goes into coal comes out again (at least within the time covered by the experiment) as carbon dioxide. The formation of water by the oxidation of a part of the hydrogen in the coal is a natural explanation for the apparent disappearance of some of this oxygen. It may also be that some of the organic compounds have been only partly saturated and hence the oxygen absorbed is not given off at once as carbon dioxide, but comes off later when the oxidation has progressed further.

Significant evidence in this connection is afforded by some experiments pursued by Varrentrapp in 1865.[a] This investigator placed fragments of fresh coal in a flask and slowly passed air (free from CO_2) through the flask and into baryta water. This operation, performed at different temperatures and carried on for varying periods of time, indicated that the amount of carbon dioxide produced was very considerable. While proceeding slowly at the ordinary temperature, a slight increase of temperature greatly augmented the output of carbon dioxide. At 150° C., the highest temperature used, 3 cubic feet of air per day passing over the coal for six days caused the formation of 103 grams of barium carbonate, which corresponds to an oxidation of 12.5 grams of carbon. As this carbon dioxide came from 250 grams of dry coal containing 64 per cent of carbon, Varrentrapp believed that if this process had been continued at 150° for about three months, all of the carbon in the coal might possibly have passed over into carbon dioxide.

These experiments seem to indicate that the oxygen absorbed by coal largely enters into chemical combination. At first when coal is exposed to the air, oxygen is absorbed and condensed on the surface, or within the minute pores, in a manner analogous to the absorption of gases by charcoal—as free, chemically uncombined oxygen. But coal holds less gas in this state than charcoal does. The oxygen thus held then passes on into chemical union with the substance of the coal, oxidizing pyrite in the presence of moisture, saturating unsaturated hydrocarbons, and directly oxidizing hydrocarbon compounds with the formation of carbon dioxide and water. As the free oxygen enters into chemical combination, more of the gas is absorbed from the

[a] Varrentrapp, F., Chem. Centralbl., vol. 36, 1865, pp. 953-954.

air; hence the process may progress steadily. The occluded oxygen, therefore, is only in a state of transition, which leads to chemical union with the coal.

DECREASE IN COMBUSTIBLE GASES.

Returning to the mine dusts, it would appear that the oxygen absorbed during the long exposure, instead of gradually becoming stored up as free gas ready to furnish rapid combustion whenever an exciting cause appears, has been steadily uniting chemically with the dust and reducing the amount of combustible matter present. A comparison of the results of the last group of tables expresses the changes which the more readily volatilized constituents of the dusts have undergone as a result of exposure. Expressed in volume of gas relative to the volume of dust, these figures are as follows:

Comparison of total volumes of specified gases obtained from dust samples.

[Relation to volume of dust as 1.]

Gas.	Old dust.	Dust exposed 2 months.	Freshly prepared dust.
Sulphur dioxide	0.10	.....	.....
Carbon dioxide	.93	0.79	0.36
Carbon monoxide	.27	.25	.08
Heavy hydrocarbons	.10	.35	.77
Methane series	.28	.45	2.37

Grouping together the carbon monoxide, heavy hydrocarbons, and methane as inflammable gas, and the carbon dioxide and sulphur dioxide as noninflammable gas, the combined figures are as follows:

Comparison of total volumes of inflammable and noninflammable gases obtained from dust samples.

[Relation to volume of dust as 1.]

Gas.	Old dust.	Dust exposed 2 months.	Freshly prepared dust.
Inflammable gases and vapors	0.65	1.05	3.22
Noninflammable gases	1.03	.79	.36

Thus the old dust yielded nearly three times as much noncombustible gas as the fresh variety, but only one-fifth as much combustible gas. The dust exposed for two months in the laboratory took an intermediate place, showing that the escape of the methane and the oxidation of the dust have proceeded in the same manner as in the mine (except, perhaps, the weathering of the pyrites), but that the process had not advanced so far in this length of time. It seems probable that with a longer exposure to the air it would reach the same condition as the old mine dust.

These changes undergone by the dust during its exposure to the air must have considerable effect on its explosive properties. The loss of much of the free methane and some of the other hydrocarbon gases and vapors, coupled with a partial oxidation of the combustible material and an increase in the volume of noncombustible gases, must, other things being equal, reduce the explosive potentialities of the dust.

The figures of the foregoing tables represent only the gas evolved when the dusts are heated to 350° C. At 450° the same general differences exist in the gases produced, though more gas is evolved than at the lower temperature, and the proportions show some variation. Much higher temperatures than this are developed during an explosion, and hence more gas may be developed and exploded. Although perhaps the basis of comparison should be the total quantity of gas developed at a higher temperature, say 600°, it seems likely that the comparative explosiveness depends more on the relative volumes of inflammable gas that can be easily and quickly generated from the dust. The heat of the explosion can operate only for a very short interval of time, so that the readily freed volatile hydrocarbons must count most. Such gases are those represented in the foregoing tables. It is the initiation of the explosion and the facility with which it is propagated that are of the most vital importance. These would seem to be less dependent on the total volume of combustible gas that may be obtained from a given volume of dust, and that may or may not ultimately participate in the explosion, than on the ease with which the generation of combustible gas can be started and the products be fed to the growing flame. It is probably also true that at temperatures above 450° C. the freshly prepared dust will yield more combustible gas and vapors than the weathered dust, though it is likely that the difference will not be so great as at the lower temperatures. The analyses of even the well-charred dust from the exploded mines indicate that only a small proportion of the total volatile matter has been lost during the explosion.

CONCLUSION—FRESH DUST MORE DANGEROUS.

Because of these considerations, the conclusion seems natural that, unless the action of the air and the general weathering processes introduce some other factors here overlooked, the newly made coal dust at the working faces of the mine should, on a chemical basis alone, other things being equal, possess greater explosive potentialities than the old dust along the main haulage ways. One of the uncertain operative factors is the occluded oxygen, which may be supposed to facilitate an explosion of dust. But if the conclusion favored by the comparative tests made on these samples of dust is valid, the quantity of oxygen within the coal dust in the free state

is not sufficient to play a very important part in an explosion. Moreover, the sample of freshly prepared dust gave off somewhat more oxygen when the tube in which it was placed was exhausted by the vacuum pump than either of the older samples. If the occlusion of oxygen from the air takes place with such rapidity, the new dust at the working faces must be essentially as predisposed to explosion, so far as occluded oxygen is concerned, as the oldest dust near the pit mouth. Hence it would seem that occluded oxygen is not a very important factor in this stage of the problem.

The physical state of the dust, however, is undoubtedly a factor of the greatest importance. Dryness and fineness of division of the dust must favor its ready inflammability, and in proportion as the dust in certain parts of a mine is drier and finer than in other sections, other things being equal, the danger of ignition from a blown-out shot or other cause must be increased. A study of the relative explosiveness of coal dusts according to their physical characteristics does not, however, constitute a part of this investigation.

Chemically the difference between fresh and old weathered dust, particularly in those respects which most vitally influence their relative explosive potentialities, as has been indicated by comparative experiments, is great. The dust which has long been exposed to the air has, compared with the freshly made dust, lost a very considerable proportion of its free methane and other readily escapable combustible hydrocarbons; has suffered the partial oxidation of a portion of its hydrocarbons,[a] and has stored up an increasing volume of the noninflammable gases, which are the products of combustion. It is probably safe to assume that the finer the dust the more rapid and complete has been this process. Therefore, unless other factors are involved which have been overlooked or whose importance has been underestimated, it would seem that, on the basis of its chemical properties, the fresh dust is likely to prove more inflammable and more predisposed to start and propagate a dust explosion, whatever the immediate precipitating cause may be, than the old dust which has long been exposed to the weathering action of the air. Entirely in accord with this conclusion is that to be drawn from the work of Professor Bedson, who found that while an electric current of 12.05 amperes would, by heating a resistance wire, ignite 1 gram of fine (100-mesh) fresh coal dust, it required a current of 14 amperes to heat the wire sufficiently to ignite a like amount of the same dust after it had been exposed to the air for about three weeks.

[a] It is to be noted that this process of oxidation, which liberates heat, is identical with that which, when the heat can not readily escape, finally causes the ignition of the coal. But the coal dust probably does not accumulate in sufficient mass to prevent the rapid loss of the heat produced by the oxidation, and hence ordinarily its temperature probably does not become greatly raised.

SURVEY PUBLICATIONS ON FUEL TESTING AND MINE ACCIDENTS.

The following publications, except those to which a price is affixed, can be obtained free by applying to the Director, Geological Survey, Washington, D. C. The priced publications can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

Bulletin 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, in St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

Professional Paper 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1,492 pp., 13 pls. $1.50.

Bulletin 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

Bulletin 323. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp. 10 cents.

Bulletin 325. A study of four hundred steaming tests, made at the fuel-testing plant, St. Louis, Mo., 1904, 1905, and 1906, by L. P. Breckenridge. 1907. 196 pp. 20 cents.

Bulletin 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907; J. A. Holmes in charge. 1908. 299 pp.

Bulletin 333. Coal-mine accidents, a preliminary report by Clarence Hall and W. O. Snelling. 1907. 21 pp.

Bulletin 334. The burning of coal without smoke in boiler plants; a preliminary report, by D. T. Randall. 1908. 26 pp. 5 cents. (See Bull. 373.)

Bulletin 336. Washing and coking tests of coal and cupola tests of coke, by Richard Moldenke, A. W. Belden, and G. R. Delamater. 1908. 76 pp. 10 cents.

Bulletin 339. The purchase of coal under government and commercial specifications on the basis of its heating value, with analyses of coal delivered under government contracts, by D. T. Randall. 1908. 27 pp. 5 cents.

Bulletin 343. Binders for coal briquets, by J. E. Mills. 1908. 56 pp.

Bulletin 362. Mine sampling and chemical analyses of coals tested at United States fuel-testing plant, Norfolk, Va., in 1907, by J. S. Burrows. 1908. 23 pp. 5 cents.

Bulletin 363. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests and some foreign specifications for briquetted fuel, by W. F. M. Goss. 1908. 57 pp., 4 pls.

Bulletin 366. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 1908. 44 pp., 8 pls.

Bulletin 367. Significance of drafts in steam-boiler practice, by W. T. Ray and Henry Kreisinger. 1909. 61 pp.

Bulletin 368. Washing and coking tests of coal at Denver, Colo., by A. W. Belden, G. R. Delamater, and J. W. Groves. 1909. 54 pp., 2 pls.

Bulletin 369. The prevention of mine explosions, by V. Watteyne, C. Meissner, and A. Desborough. 1908. 108 pp.

Bulletin 373. The smokeless combustion of coal in boiler plants, by D. T. Randall and H. W. Weeks. 1909.

INDEX.

Page.

After damp, collection of..... 7-8
  percentage of, in mine air..... 11-14, 28
Ash, proportion of, in coal dust..... 46
Barometric changes, effect of, on gas discharge..... 37-39
Beard, J. T., on mine explosions..... 11-12
Bedson, Prof. ——, on dust explosions..... 64
Bibliography..... 65
Blowers, escape of gas from, effect of barometric changes on..... 88-89
  occurrence of..... 36-37
Brookmann, V., on mine explosions..... 12
Charred dust, analyses of..... 46, 49, 51
  character and distribution of..... 44-45
  loss of volatile matter in..... 50
  See also Coal dust.
Coal, absorption of oxygen by..... 60-62
  bottling of, in vacuum, gases from..... 24-39
    gases from, analyses of..... 26
      character of..... 25-31
      comparison of, with mine gases.. 31
      volume of..... 24-25, 29
  crushing of..... 17-18
    gas from, analyses of..... 18, 19, 40, 41
      conclusions on..... 30
      determination of..... 17-23
      volume of..... 20-23
  heating of, gases from..... 39-42
  specific gravity of..... 47
Coal dust, age of, importance of..... 56-64
  age of, relation of, to combustible gases . 62-63
  analyses of..... 49, 51, 57
  character of..... 44-45
  deposits of, by explosion..... 44-45
  effects of..... 44-46
    explanation of..... 46-48
  explosions due to..... 14, 43
  gases from..... 42
    decrease of, with age..... 62-63
  samples of..... 45-46
  studies on..... 42-54
  See also Charred dust.
Cold weather, beginning of, influence of, on explosions..... 54-55
Coking, cause and manner of..... 48-49
  coal dust affected by. *See* Charred dust.
  nature of..... 49
Dampness, effect of, on explosions..... 52-55
Darr mine, analyses of..... 46
  air in..... 15-16
  coal dust in..... 43, 44, 51-52
    analyses of..... 51
  explosion in..... 6
  gases in..... 9-10, 11, 14
    analyses of..... 8-9
  water in, explosion checked by..... 53-54
Dust. *See* Coal dust; Shale dust.
Fairmont Coal Company, mines of. *See* Monongah.
Fire damp, collection of..... 7-8

Page.

Fire damp, explosion of..... 43
  percentage of, in mine air..... 9-10
  See also Methane.
Galloway, William, on coal dust..... 45
Gases, mine, analyses of..... 8-9, 31
  chemical production of, by heat..... 40-42
  collection of..... 7-8
  difference between heat gases and..... 39
  origin of..... 31-32
  possible conditions in..... 16-17
  sources of..... 16-17
  See also Methane.
Hall, Clarence, work of..... 6
Heat, gases obtained from coal by..... 39-42
Heise and Herbst, on gas pressures..... 39
  on mine explosions..... 12
Literature, list of..... 65
Lord, N. W., on coal dust analysis..... 50
Methane, escape of, rate of..... 33-36
  escape of, rate of, diagram showing..... 34
    rate of, effect of barometric changes on..... 37-39
      significance of..... 36-37
  percentage of, in coal gas.. 9-10, 27, 33-36, 42-43
  See also Fire damp; gases, mine.
Mine gases. *See* Gases, mine.
Moisture, effect of, on explosions..... 52-55
Monongah mine, air in..... 15
  dust samples from..... 45
    See also Coal dust.
  explosion in..... 6
  gases in..... 11
    analyses of..... 8
Naomi mine, air in..... 15
  dust from..... 51
    analysis of..... 51
  explosion in..... 6
  gases in..... 10, 11
    analyses of..... 8
Nitrogen, percentage of..... 28
Oxygen, absorption of, by coal..... 60-62
  deficiency of..... 15-16
  need of, by explosions..... 51
Palladium, gas from..... 17-18
Paul, J. W., work of..... 6
Pittsburgh Coal Company, mine of. *See* Darr mine.
Reservoirs, gas in..... 37
Shale dust, effect of, on explosions..... 47, 53, 55-56
  specific gravity of..... 47
Snelling, W. O., on moisture in coal-mine air. 54
  work of..... 6
United Coal Company, mine of. *See* Naomi mine.
Vacuum bottles, description of..... 24
Varrentrapp, F., on absorption of oxygen by coal..... 61
Ventilation, dangers of..... 54-55
Volatile matter, loss of, by explosion..... 49-51
Whitewash, effect of, on explosions..... 55
Workings, old, gas from..... 36

O

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 384

A GEOLOGICAL RECONNAISSANCE

IN

NORTHERN IDAHO AND NORTHWESTERN MONTANA

BY

F. C. CALKINS

WITH

NOTES ON THE ECONOMIC GEOLOGY

BY

D. F. MACDONALD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

CONTENTS.

	Page.
INTRODUCTION	7
CHAPTER I. Geography	10
General physiographic relations	10
Principal topographic features	13
General statement	13
Mountain ranges	13
Cœur d'Alene Range	13
Definition	13
Character	14
Cabinet Range	14
Definition	14
Character	14
Purcell Range	16
Definition	16
Character	16
Major depressions and drainage features	16
Purcell trench	16
Kootenai Valley	17
Clark Fork-Flathead Valley	18
Cœur d'Alene Valley	18
Missoula Valley	19
Lakes	19
Climate and vegetation	20
Industries	21
Routes of travel	22
Settlements	25
CHAPTER II. General summary of the geology	27
Preliminary outline	27
Stratigraphy	33
Ancient schists and gneisses	33
Algonkian rocks	35
General statement	35
Prichard formation	35
Ravalli group	37
Newland formation	38
Striped Peak formation	38
Strata above Striped Peak formation	39
Regional correlation	39
Supposed Paleozoic rocks	42
Igneous rocks	43
General statement	43

CHAPTER II. General summary of the geology—Continued. Page.
Stratigraphy—Continued.
Igneous rocks—Continued.
Acidic intrusives 43
Quartz monzonites 43
General distribution 43
Hayden Lake area 43
Chilco Mountain area 44
Areas along Purcell trench 44
Granodiorite 45
General distribution 45
Areas on Lake Pend Oreille 45
Area at west base of Cabinet Range 46
Lightning Creek area 46
Area east of Bull Lake 46
Syenite 46
Occurrence 46
Petrography 46
Basic intrusives 47
Lamprophyre 47
Occurrence 47
Petrography 47
Diorite 48
Occurrence 48
Petrography 48
Volcanic rocks 50
Algonkian volcanics 50
Occurrence 50
Petrography 50
Miocene basalt 51
Occurrence 51
Character 51
Structure 52
General statement 52
Faults 52
General character and expression in topography 52
Description of principal faults 53
Lenia fault 53
Snowshoe fault 54
Hope fault 55
Bull Lake fault 55
Evidences of faulting along Purcell trench 56
Folds 56
CHAPTER III. Areal geology 58
General statement 58
Detailed descriptions 58
Cœur d'Alene and Spokane valleys 58
Between Cœur d'Alene and Pend Oreille lakes 59
Lake Pend Oreille 60
Clark Fork Valley below Vermilion Creek 63
Bull Lake Valley 65
Observations along Bull River 65
Bull Lake fault 66
Sediments east of Bull Lake fault 68

CHAPTER III. Areal geology—Continued. Page.
Detailed descriptions—Continued.
Kootenai Valley from Troy to Bonners Ferry 68
Lower Yaak Valley 70
Purcell Mountains 71
Mooyie Valley 71
Vicinity of forty-ninth parallel east of Mooyie crossing 71
Yaak Basin 73
Divide at head of South Fork of Yaak River 74
Kootenai Valley from Troy to Jennings 75
Section between Troy and Libby 75
Between Libby and Jennings 77
East side of Cabinet Range 77
General features of topography and geology 77
Topography 77
General geology 78
Section southwest of Libby 78
Section east of Bear Peak 79
Observations near head of Fisher River and on Vermilion Creek 81
Swamp Creek 82
Clark Fork-Flathead Valley from Vermilion Creek to Dixon 83
Vermilion Creek to Thompson 83
Prospect Creek 85
Gorge between Thompson and Plains 85
Plains to Dixon 88
North side of Missoula Valley 88
Vicinity of Lothrop 88
Lothrop to Iron Mountain 89
Iron Mountain to Paradise Spring 91
CHAPTER IV. Notes on the economic geology, by D. F. MacDonald 92
Introductory statement 92
Descriptions by localities 94
Pine Creek district 94
General features 94
Mines and prospects 94
Outlook for the district 95
Lake Pend Oreille district 95
Vicinity of Lakeview 95
General features 95
Mines and prospects 96
Production 96
Outlook 97
Lime plant at Squaw Bay 97
Western shore 97
Eastern shore 98
General conditions 98
Prospects 98
Troy district 99
Mines on Callahan Creek 99
Grouse Mountain properties 102
Sylvanite 102
Location 102
Mines 103

CHAPTER IV. Notes on the economic geology—Continued. Page.
Descriptions by localities—Continued.
Snowshoe mine 103
General statement 103
Location 103
Character of vein 103
Ores 104
Plant 104
Future prospects 104
Cabinet district 105
Location 105
Silver Butte mine 105
Mines at head of Fisher River 105
Prospect Creek district 106
Location 106
Mines and properties 106
Missoula Valley 106
General statement 106
Iron Mountain mine 107
Mining properties not visited 107
Outlook for the region 108
INDEX 109

ILLUSTRATIONS.

Page.
PLATE I. Geologic sketch map of portions of northern Idaho and northwestern Montana 26
II. Views on Lake Pend Oreille 62
FIGURE 1. Index map 8
2. Landslide west of Bull Lake 66
3. Diagrammatic section across Bull Lake fault 67

A GEOLOGICAL RECONNAISSANCE IN NORTHERN IDAHO AND NORTHWESTERN MONTANA.

By F. C. Calkins.

INTRODUCTION.

During the field seasons of 1903 and 1904, I was engaged, under the supervision of Mr. F. L. Ransome, in mapping the areal geology of the Cœur d'Alene district in Montana. The rocks of that district consist mainly of a thick series of old sediments, in which no fossils were found and which are presumably of pre-Cambrian age. On all sides of this known territory lie extensive tracts of land which were then almost unknown, geologically, but were supposed, from the fragmentary information available, to be also occupied in the main by pre-Cambrian sediments. It was believed, indeed, that the Cœur d'Alene district lay in the same great zone of pre-Cambrian sedimentation in which lie certain areas in the Rocky Mountains where stratigraphic studies had previously been made by Messrs. Walcott,[a] Weed,[b] and Willis.[c] It was primarily with the object of correlating the Cœur d'Alene section with the ones, not obviously resembling it, which have been described by those authors, and of observing the changes undergone by the formations of the Cœur d'Alene district in their extension to the north and east, that, at the suggestion of Mr. Ransome, the reconnaissance of which this paper is to give an account was undertaken.

The field work was begun early in July, 1905, and carried on continuously until October 1. During this period the exploring party and its camp equipage were transported by means of saddle horses and a pack train. In October this work was supplemented by foot traverses along the main line of the Northern Pacific Railway between Thompson Falls and Dixon, and in Missoula Valley and the

[a] Walcott, C. D., Pre-Cambrian fossiliferous formations: Bull. Geol. Soc. America, vol. 10, 1899, pp. 199–244; Algonkian formations of northwestern Montana: Bull. Geol. Soc. America, vol. 17, 1906, pp. 1–28.

[b] Weed, W. H., Description of Little Belt Mountains, folio (No. 56): Geol. Atlas U. S., U. S. Geol. Survey, 1899; Fort Benton, folio (No. 55): Geol. Atlas U. S., U. S. Geol. Survey, 1899; Geology and ore deposits of Little Belt Mountains: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 257 et seq.

[c] Willis, Bailey, Stratigraphy and structure, Lewis and Livingston ranges, Montana: Bull. Geol. Soc. America, vol. 13, 1902, pp. 305–352.

hills north of it. An idea of the extent and location of the area studied may be gained from the index map (fig. 1), and the amount of observation upon which this report is based may be roughly estimated from an inspection of the main routes of exploration, which are shown on Plate I. It will be evident from a comparison of the time employed with the area surveyed that the work was necessarily of a relatively hurried nature, and this must serve to explain the lack of completeness and finish in the results obtained.

The purposes formulated at the inception of the undertaking were substantially accomplished. The stratigraphic divisions of the

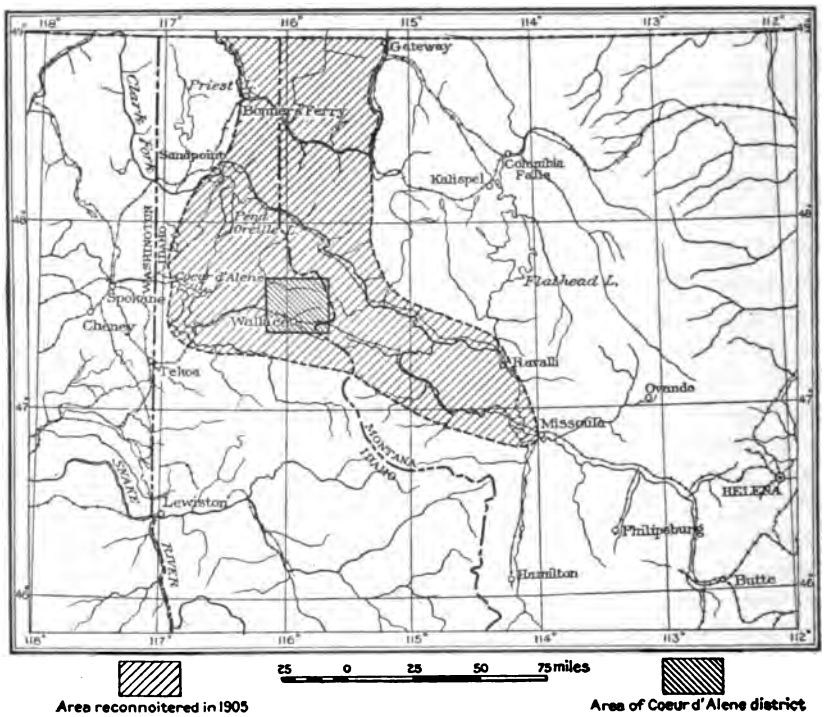


FIGURE 1.—Index map showing location of area described.

Cœur d'Alene section were traced northward and eastward, most of them to the boundaries of the area covered, and others to gradual disappearance. On the north, connection was made with a zone studied during the season of 1904 by Dr. R. A. Daly,[a] of the Canadian Survey, and on the east a junction was practically attained with an area studied simultaneously by Mr. Walcott. Correlation of the Cœur d'Alene section with sections worked out by Mr. Walcott was made, thus fixing certain horizons in the stratigraphic column over a very extensive area. The season's work of Mr. Walcott, fortunately

[a] See geology of the western part of the international boundary: Summary Rept. Geol. Survey of Canada for 1904, 1905, pp. 91–100.

providing a connecting link between the Cœur d'Alene section and those farther eastward previously described, enabled him to make correlations between the different Algonkian sections of a vast area in Montana, Idaho, and British Columbia, and to show the applicability throughout this region of the term Belt "terrane," applied to the Algonkian in that part of the region first carefully studied.

In both field and office I was efficiently assisted by Mr. D. F. MacDonald, and the work of examining mines and prospects was delegated in greater part to him. The brief account of the region's mineral resources appended to this report is substantially similar to one prepared for Bulletin 315, with the addition of some information concerning recent developments, and of some details which it was deemed advisable to omit from the sketch that appeared in that bulletin.

The report has profited by the criticisms of Mr. Ransome, who carefully read the manuscript, and to whom my thanks are offered for many helpful suggestions.

Acknowledgments are due to many owners and managers of mines and prospects in the region examined, who, without exception, freely offered facilities for inspection of the properties in their charge.

Mr. Leiberg, the owner of much land on the southwest shore of Lake Pend Oreille and of prospects on Little North Fork of Cœur d'Alene River, devoted a day to guiding us about the vicinity of Chilco Mountain and supplied considerable information concerning the geology in the vicinity of the lake. For his assistance cordial thanks are tendered.

Acknowledgments are due also to the courtesy of Mr. F. J. Whitney, passenger traffic manager of the Great Northern Railway, and of Mr. A. M. Cleland, general passenger agent of the Northern Pacific Railway, who most obligingly furnished detailed maps of the portions of their respective lines which cross the region surveyed.

CHAPTER I.

GEOGRAPHY.

GENERAL PHYSIOGRAPHIC RELATIONS.

The traveler who crosses the continent on the Great Northern Railway is continually surrounded by mountains from the time he enters a breach in the wall of the eastern front of the Rockies, which looks out over the ocean-like expanse of the Great Plains, until, near the city of Spokane, he reaches the eastern border of that arid and monotonous tract known as the Columbia Plain, which he must cross before entering the forest-covered Cascade Range. In this part of his journey he will have traversed a relatively narrow section of the main chain of a mountain system which extends almost unbroken from the extremity of the Alaska Peninsula to Cape Horn. South of his line of travel this essentially mountainous zone gradually broadens. It is limited on the east by the Great Plains and is separated on the west from the continuous chain of the Cascade and Sierra Nevada ranges by a region in which well-defined and comparatively short ridges divide broad stretches of barren plain. Almost immediately north of his route it expands abruptly on the west. The northern boundary of the Columbia Plain is a sinuous line, the average direction of which is nearly east and west, and which does not depart greatly from the forty-eighth parallel of latitude. It marks the southern limit of a tract occupied by mountain ridges of moderate and approximately uniform elevation. North of this boundary the western mountains of the North American continent form a zone divided into subordinate groups by some great valleys but interrupted by no areas of level ground at all comparable in magnitude with the Columbia Plain.

The attention of the reader may now be narrowed to the area bounded on the north and south by the forty-ninth and forty-seventh parallels of latitude, on the east by the Great Plains, and on the west by the meridian of Spokane. This area includes the field of this reconnaissance and contains, in addition, parts of the great physiographic divisions that border it.

The mountains of this area are divisible into groups of at least two orders of magnitude. For most of the region the task of outlining these groups and of putting their nomenclature, which was long confused and illogical, into orderly form has been admirably accom-

plished by Daly.[a] Daly's paper appeared after my return from the field, but, having recognized in the area which I had explored essentially the same major physiographic units that Daly has pointed out, I was prepared to accept his conclusions in all essential particulars. He has placed under material obligation all who are interested in the geography of the northwestern part of the continent.

As Daly has shown, the limits of the natural orographic groups of this region are certain major valleys. The mountains comprised within the area outlined above are divided into groups of the first order by two linear depressions of remarkable length. As each is occupied not solely by one stream but by numerous streams and lakes, they can not be designated, as are most topographic features resembling them in form, by the term "valley" coupled with the name of a river. Daly applies to them the term "trench," which well connotes their comparative uniformity of cross section and their approximate straightness.

The more eastern of these depressions, which limits a long and narrow orographic zone that Daly calls the Rocky Mountain system, he has named the "Rocky Mountain trench." This extends as "a narrow and wonderfully straight depression" in a northwesterly direction for about 800 miles from the head of Flathead Lake. South of this lake the depression does not continue with so characteristic and regular a form, but it seems best to consider, for reasons which will presently be discussed, that its rôle as a boundary between mountain groups of the first rank is taken up by a zone of low land occupied by Flathead Lake, part of Flathead River and Jocko Creek, and, south of the region here considered, by Bitterroot River.

The more western depression, named by Daly the "Purcell trench," joins the Rocky Mountain trench about 200 miles north of the international boundary, and is considered by him as terminating at the south near Bonners Ferry. But it seems more reasonable to consider it as extending at least to the southern end of Lake Cœur d'Alene, about 80 miles south of Bonners Ferry. It is true that the southern part of the "Purcell trench," if the application of the term be so extended, has not the striking regularity of the more northern part, but it is none the less a definite and persistent zone of depression, remarkable for the discordance of its direction with the prevailing trend of the major streams.

Each of the three orographic divisions marked off by the Purcell and Rocky Mountain trenches is distinguished by certain broad characteristics, which may be indicated briefly before proceeding to a more detailed description of the area in which the geologic reconnaissance of 1905 was carried on.

[a] Daly, R. A., The nomenclature of the North American Cordillera between the forty-seventh and fifty-third parallels of latitude: Geog. Jour., vol. 27, No. 6, June, 1906, p. 586.

The easternmost of these divisions is that designated by Daly the Rocky Mountain system,[a] and is comprehended between the Great Plains and the Rocky Mountain trench. It is characterized by a development of the principal streams chiefly in a longitudinal direction, which south of the forty-ninth parallel is about north-northwest. In consequence of this the belt consists of a number of overlapping ranges having the same direction, the principal ones being the Lewis, Livingston, and Galton, near the international boundary, and the Kootenai, Mission, and Swan ranges, farther south. The topography of these ranges is generally bold, and elevations of 8,500 to more than 10,000 feet are attained by many of their peaks. Daly does not include the Mission Range in the Rocky Mountain system; his map[b] shows this range as separate from the grander division on the east. But, as has been suggested on a preceding page, it is to some extent a matter of choice whether we shall consider the Rocky Mountain trench as continued southward by the depression containing Flathead Lake and part of Jocko Creek or by the valley of Swan River. To me, who have not had the advantage of actual observation in the critical area, there seem to be two reasons for preferring the former alternative. In the first place, the first-named depression, so far as can be judged from available maps, continues much farther south than the second, and is therefore of more practical use. In the second place, the Mission Range is closely allied to the mountains east of it by proximity, by identity of trend, and by being strongly contrasted in the last-named respect with the far less rugged elevations west of the main Flathead River.

The next great division west, lying between the Rocky Mountain and Purcell trenches and comprising the Cœur d'Alene, Cabinet, Flathead, and Purcell mountains, has a less strongly accentuated relief than Daly's "Rocky Mountain system." Except in a part of the Cabinet Range, few of its peaks notably surpass 7,500 feet, and on the whole only a small proportion of its summits attain 7,000 feet. The more important stream valleys, in contrast to those of the eastern zone, have an average direction of about west-northwest, and it is these streams that form the boundaries between the chief subdivisions worthy to be distinguished by separate names.

The great orographic division immediately west of the Purcell trench is designated by Daly the Selkirk system. As defined by him, it is bounded on the west by a section of the Columbia River valley having a nearly meridional direction, and on the south by the Colum-

[a] Daly's definition of that system is at variance with the usage prevailing in the United States and embodied in a recent decision of the United States Geographic Board. This makes the term embrace the whole of the mountainous region north of the Colorado Plateaus, which is limited on the east by the Great Plains and on the west by the Great Basin and the Columbia Plain.

[b] Daly, R. A., The nomenclature of the North American Cordillera between the forty-seventh and fifty-third parallels of latitude: Geog. Jour., vol. 27, No. 6, June, 1906, p. 588.

bia Plain. But the latter part of the definition is hardly adequate and leaves one in doubt as to just how far south the Selkirk system should be considered to extend. East of longitude 117° 30′ the border of the Columbia Plain, although rather sinuous, has a general direction more nearly north-south than east-west. It therefore approaches the line of the Purcell trench. But so far as I am aware these two great natural boundaries do not quite meet. Still, as the height of the hills between them diminishes southward at the same time that their breadth decreases, it is perhaps sufficiently definite to consider the Selkirk system as gradually tapering to an end somewhere near the southern end of Lake Cœur d'Alene. It would thus include a group of hills lying south of Spokane River between Spokane and the lake.

The topographic character of so much of the Selkirks as was seen during the work on which this paper is based is in general similar to that of the mountains between the Purcell and Rocky Mountain trenches. Near the boundary they are moderately rugged and attain to heights of nearly 7,000 feet, but south of Spokane River they are gently rounded and few of their summits rise higher than 5,000 feet above sea level. The major drainage lines north of the valley of Clark Fork of Columbia River trend north and south, but in the southernmost part of the system they trend nearly east and west.

PRINCIPAL TOPOGRAPHIC FEATURES.

GENERAL STATEMENT.

The field covered by this reconnaissance lies, as the map forming Plate I shows, almost entirely within the great zone comprised between the Purcell and Rocky Mountain trenches. It slightly overlaps the Purcell trench at the west, but does not, on the other hand, comprise the "Flathead Mountains" of Daly, which lie east of the Cabinet Range and west of the Rocky Mountain trench. The main physical features of this field will now be enumerated and described. The limits and character of the mountain ranges will first be set forth, and then some of the principal features of the drainage will be considered.

MOUNTAIN RANGES.

CŒUR D'ALENE RANGE.

Definition.—The Cœur d'Alene Range is the southernmost in this region. The definition of its limits has not been generally agreed upon, so that the one put forth here may be considered as provisional. The use of the term here adopted is that suggested by Lindgren,[a] who defines the range as extending from Lake Pend Oreille at the

[a] A geological reconnaissance across the Bitterroot and Clearwater mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1907, p. 23.

northwest to the vicinity of Lolo Pass, beyond the southern limit of the area shown on Plate I. Its form is rudely triangular. Its southern boundary is rather vague, but should probably be considered as formed in greater part by the rim of the drainage basin of Clearwater River. For a short distance near its southwest corner it adjoins the Columbia Plain, but most of its western boundary is constituted by the Purcell trench. Its northeastern border is considered as being formed by the valleys of Clark Fork, Flathead River, and Jocko Creek.

The watershed of the range, as thus defined, forms a divide between Clark Fork of Columbia River and the main trunk of that stream. Its two versants are extremely unequal in area, the northeastern being drained by short creeks that flow directly into Clark Fork and Flathead River, and the southwestern by several long and much ramified streams whose waters are gathered into Spokane and Snake rivers.

Character.—As a whole the Cœur d'Alene Range has a less diversified relief than the ranges north of it. Viewed from high stations it shows a rather monotonous expanse of ridges that are nearly equal in height and have nearly level crests without markedly prominent summits. Its general aspect is therefore similar to that of a maturely dissected plateau. The general level of this upland, in its central and highest part, is a little above 6,000 feet, although a few of its peaks rise nearly 7,000 feet above the sea. To the west the general equality of summit levels is not so marked, for the valleys have been more extensively cut out, so as to destroy any regularity of level that the ridges may once have had. About Pend Oreille and Cœur d'Alene lakes few of the summits are more than 5,000 feet high.

CABINET RANGE.

Definition.—The Cabinet Range is here considered as extending from Bonners Ferry southeastward to the junction of Jocko Creek with Flathead River. Its boundaries, in the part with which a relatively thorough acquaintance was gained during this reconnaissance, are quite definite. Its west side is bordered by the Purcell trench, and its southwest side by the nearly straight valley occupied mainly by Clark Fork of Columbia River and partly by Flathead River. The character of its most eastern part was not so thoroughly learned and its boundary on that side is apparently less definite. It seems reasonable to follow Daly in considering the southern part of its eastern boundary as constituted by the valley of Little Bitterroot River with a short portion of Flathead River, and the northern part by the valley of Fisher Creek.

Character.—The Cabinet Range as a whole is somewhat loftier than the Cœur d'Alene Mountains, and far more diversified in

character. It is divided into two fairly distinct portions by a north-south valley or trench, near whose center lies Bull Lake. The portion of the range west of this trench is of the dissected plateau type, but because of the hardness of the rocks from which it has been carved and the intense alpine glaciation to which it has been subjected the details of its sculpture are highly picturesque. The most rugged scenery in this section of the range is found about Scotchman Peak and to the east of it, where the country rock is quartzite. The northern, eastern, and western faces of the peaks in this vicinity overlook great amphitheaters, from many of which the summits are not directly accessible.

The valley that divides the range affords an easy-graded wagon route from Smeads Crossing to Troy. It is broad compared with its length, except along the lower part of Bull River, and its highest part is only about 700 feet above Clark Fork of the Columbia. The pass is in an area of moraines, south of which are extensive meadows whence the waters of the united forks of Bull River flow southward. Just north of the divide lies Bull Lake, draining through Lake Creek northward, although erroneously shown on most maps as draining to the south. The depth to which the range has been channeled by this transverse valley is emphasized by the fact that some of its highest and most jagged peaks overlook the valley on the east.

It is in the portion of the Cabinet Range extending about 25 miles southeastward from Bull Lake that one finds the most impressive alpine scenery of the region. Even in distant views from the heights of the Cœur d'Alene Mountains or of the Purcell Range the superior elevation and deeply serrate sky lines of the mountains in this vicinity set it in striking contrast with the surrounding expanse of lower and more even-crested ridges. What is believed to be the highest summit of the range, its elevation being estimated barometrically as between 8,500 and 9,000 feet, is Bear Peak, which rises at the head of Bull River. Toward this stream it presents a smooth and moderate slope, but its northern and eastern faces are deep cirques with precipitous sides. In the northern cirque is a small glacier, a remnant of those which once flanked all the higher peaks of the region.

A number of lofty and rugged peaks are aligned to the south of Bear Peak, and it is rivaled in height—possibly surpassed—by Great Northern Mountain, near the southern end of the column, which also seems to carry a glacier. Near the head of Fisher River the average level of the crests diminishes abruptly by about a thousand feet, and a topography of pyramids and spires gives way to monotonously level and gently rounded ridges like those characteristic of the Cœur d'Alene Mountains. Southeastward from this pass the range was not explored, but, to judge from maps and distant views,

it seems that the mountains diminish further in height and become more and more dissected by low-grade valleys.

PURCELL RANGE.

Definition.—The Purcell Range, as defined by Daly, trends about north-northwest. It is for the most part bounded on the east by the Rocky Mountain trench and on the west by the Purcell trench, the remainder of its boundary being defined by the valley of Kootenai River from Gateway, where it leaves the former trench, to Bonners Ferry, where it enters the latter. That minor portion of it which lies in the United States is embraced by the great bend of Kootenai River between the points where it crosses the boundary.

Character.—This southern portion of the Purcell Mountains is divided into three subdivisions by Mooyie and Yaak rivers.

West of Mooyie River, between its valley and that of the Kootenai, is a range trending almost due north and south and having comparatively simple topography. About 5 miles south of the international boundary this range is crossed by one of the remarkable flat-bottomed low-grade valleys so numerous in the region. The crests of its ridges are comparatively even in height and bear no conspicuous peaks.

The mountains dividing the Mooyie from the Yaak drainage are in greater part of a gentle character and are heavily wooded where they have not been swept by forest fires. The main divide, however, from a short distance south of the international boundary to Mount Ewing, several miles farther south, is a somewhat more elevated, rocky ridge, and at the south end of the chain is also a group of jagged summits. The maximum elevation of the range is about 7,500 feet.

The mountains east of Yaak River have the same general character as those west of it. The divide, surrounding the broad basin of Yaak River, comprises most of the higher points, of which at least one exceeds 7,500 feet in height.

MAJOR DEPRESSIONS AND DRAINAGE FEATURES.

PURCELL TRENCH.

The ground plan of that portion of the Purcell trench which lies south of the forty-ninth parallel is rudely indicated on Plate I by the tint appropriate to the Quaternary deposits that cover most of its bottom. This part of the depression varies considerably in width and topographic character. On the basis of these variations it may be considered as comprising four sections, which, in order from north to south, extend respectively (1) from the forty-ninth parallel to Bonners Ferry, (2) from Bonners Ferry to Lake Pend

Oreille, (3) from Lake Pend Oreille to Spokane River, (4) from Spokane River to the south end of Lake Cœur d'Alene.

The northernmost section, between the forty-ninth parallel and Bonners Ferry, where Kootenai River enters the trench, has a flat, marshy bottom 2 or 3 miles wide, bounded on either side by mountains. Those on the west rise abruptly, while those on the east slope more gently at the south but precipitously at the north. In the flat bottom Kootenai River ordinarily meanders between reedy banks, with broad windings and glassy surface, but in time of freshet it floods the entire valley from one mountain wall to the other.

From Bonners Ferry to Lake Pend Oreille the trench has the same topographic character as to the north, but is not occupied by any master stream. The northern part is drained by a small tributary of Kootenai River, the southern part drains into the lake by way of Sand Creek, and the middle part is drained by Pack River. This stream, remarkably enough, flows directly across Purcell trench and, making its way eastward to Lake Pend Oreille through another low-grade valley, cuts off from the main Cabinet Range a triangular mass of hills.

South of the lake the trench is neither so regular nor so definitely bounded as it is northward. The hills on either side are lower than to the north and are broken by several broad, level-bottomed valleys. The width of Rathdrum Valley diminishes near Cocolalla Lake to about a mile, then expands to about 9 miles in the gravelly plain that embraces what are locally known as Rathdrum and Eightmile prairies.[a] This "prairie" section has no surface drainage except Clark Fork. In several canyons that open into it are small lakes, the waters of which seep into the great sheet of gravel that holds them back, and doubtless finally make their way into Spokane River, whose valley forms a broad avenue into the great plain of the Columbia.

South of Spokane River the Purcell trench, somewhat constricted, is occupied by the main body of Cœur d'Alene Lake, on either side of which rise rounded hills, with high terraces of basalt on their flanks.

KOOTENAI VALLEY.

The valley of Kootenai River east of Bonners Ferry is markedly different in character from the Purcell trench. The part lying within the field of this reconnaissance is nearly all narrow as compared with the Purcell trench, and for most of the distance between Gateway and Bonners Ferry the turbid pale-green waters of the stream flow swiftly between steep rocky banks. Not everywhere do

[a] See Sandpoint and Rathdrum sheets, Topographic Atlas U. S., U. S. Geol. Survey.

the canyon walls rise to a great height, for a broad terrace, partly cut in rocks and partly built of gravel and sand, is generally developed at a height of several hundred feet above the river. From Libby to the east side of Lake Creek valley, however, the slopes rise steeply from the water's edge to a height of several thousand feet, and near the middle of the gorge thus formed there is a low cataract in the river. Where the broad valleys of Lake Creek and Libby Creek enter from the south are expansions which afford room for the towns of Troy and Libby.

CLARK FORK–FLATHEAD VALLEY.

The boundary between the Cabinet and Cœur d'Alene ranges is the nearly straight depression extending from Lake Pend Oreille southeastward to the mouth of Jocko Creek. The greater part of this depression is occupied by Clark Fork of Columbia River, but the portion east of the mouth of the stream locally known as Missoula River, which joins the Flathead at a right angle, is occupied by Flathead River. The depression between the two ranges mentioned may therefore be referred to as the Clark Fork–Flathead Valley.[a] This valley is somewhat similar in character to that of Kootenai River, but its sides have on the whole rather gentler slopes. For some miles east of Pend Oreille Lake the bottom lands are broad and are often flooded in time of freshet, and terraces at various levels up to about a thousand feet above the river are very extensively developed as far east as Smeads Crossing. There the valley is somewhat constricted, but broadens eastward and becomes several miles wide at Thompson Falls. Between this expansion and another known as Horse Plains there is an imposing gorge, with cliff-like walls on either hand. Above Horse Plains, also, the sides of the valley are rugged, steep, and close together, until they subside and separate in the gently rolling country of the Flathead Reservation.

CŒUR D'ALENE VALLEY.

The valley occupied by the main trunk of Cœur d'Alene River and its South Fork is a remarkably straight depression, whose position was probably determined by easy erosion along a zone characterized by extensive faulting. At Kingston the North Fork, which is considerably larger than the South Fork, enters this depression. Below the junction the valley becomes on the whole gradually broader down to its mouth at Cœur d'Alene Lake, and its floor, in this lower portion, is one great expanse of meadow land, which is annually flooded by the river. At the mouths of many of the ravines that enter

[a] The United States Geographic Board, in a recent decision, has made the name of Clark Fork of Columbia River applicable to the streams now known as Missoula River, Hellgate River, Deer Lodge Creek, and Silver Bow Creek.

it there are small lakes, precisely similar in character and origin to those about the borders of Rathdrum Prairie. (See p. 17.) The valley of the South Fork is for the most part rather broad, although it passes through a gorge between Mullan and Wallace, while the valley of the North Fork is of canyon-like dimensions through most of its course, but contains some expanded parts about half a mile wide. It is far more tortuous than the South Fork Valley, probably owing to the lack of the directive influence of great faults.

MISSOULA RIVER VALLEY.

The valley of the stream known as Missoula River is one of the larger depressions of the region. That portion which lies between the mouth of St. Regis River and the basin in which the town of Missoula is situated is as a whole relatively broad and open.

The present channel of the river, however, is a steep-sided and tortuous canyon intrenched in the bottom of a wider valley floor developed in an earlier stage of topographic history. Near the mouth of St. Regis River the Missoula, turning sharply to the right, enters a profound and steep-sided gorge, by which it crosses the northern part of the Cœur d'Alene Mountains and joins Flathead River.

The principal tributary of Missoula River in this region is St. Regis River, which heads near Sohon Pass and flows in a rather narrow and relatively straight canyon. This stream is followed to its head by the Cœur d'Alene branch of the Northern Pacific Railway, which, after crossing a high and difficult pass, descends to the valley of the South Fork of Cœur d'Alene River.

LAKES.

The region has innumerable lakes, of which the great majority are small glacial tarns in high amphitheaters. Only the two large lakes of the western part of the mountains deserve especial notice.

Both Lake Cœur d'Alene and Lake Pend Oreille have the topographic character of drowned valleys with several ramifications. Both are held in on the west by gravel dams. Their shores are constituted in part by cliffs of rock that plunge as precipitously beneath the water as they rise above it (Pl. II, *A* and *B*); in part by more gentle rock slopes or shelving beaches of shingle. The principal streams entering them are forming deltas, which indeed constitute the valley bottoms for some miles upstream from the lakes. All these features are well illustrated in Pend Oreille Lake. The southern arm has a somewhat fiordlike character, although its walls are broken by many canyons with gently sloping sides. The south shore of the eastern arm is precipitous, but much of the western portion of the lake is bordered by gravel beaches. The meadow lands at the

head of the lake have all the characteristics of a true delta, which the river, divided into three branches, overflows when swollen by melting snow.

CLIMATE AND VEGETATION.

The climate of northern Idaho and northwestern Montana is similar in general character to that of the other northwestern interior States. The year is divided into a dry and a wet season, the former beginning near October 1 and the latter about June 15, but they are not sharply marked off from each other. Thunder showers were frequent in July, 1905, and occasional rains may be expected in any of the summer months. The summers are exceptionally mild and agreeable, the days being never oppressively warm and the nights always cool. Conditions are favorable for efficient field work from about July 1 to October 1, after which considerable snow is likely to fall on the hills, while in November it may begin to lie in the valleys. Snow does not persist throughout the year upon any slopes much exposed to the direct rays of the sun, but on the steep northern faces of many of the higher peaks it forms perennial banks, and, as already mentioned, one or two small glaciers yet linger in the Cabinet Range. This fact is somewhat remarkable inasmuch as far higher peaks in west-central Montana have long been free from glaciers. There is little difference of latitude or of temperature in the two regions, and the longer persistence of glaciers in the Cabinet Range is probably due to its receiving a larger amount of precipitation.

The region was once heavily clothed with coniferous forest, but is now devastated by fires, which yearly throw a veil of smoke over the land during the summer months.

The character of the primeval forest varies according to latitude, altitude, and conditions of exposure. The size of the trees decreases toward the north, and while on the slopes of the Cœur d'Alene Mountains trees 2 or 3 feet in diameter are not uncommon, along the international boundary the lancelike trunks of tamarack, spruce, and lodgepole pine, few of which are more than a foot in diameter, constitute most of the forest.

The terrace lands of the principal river valleys support great open groves of yellow pine and tamarack, almost devoid of underbrush, that have a stately, parklike beauty. The adjacent mountain slopes bear a denser cover of fir, spruce, and tamarack, which with increasing elevation gives way to open growth of small, regularly formed spruces underlain by an often luxuriant carpet of grass.

The fires have perhaps made their most severe ravages in the western part of the area. Some decades ago the hills about Lake Pend Oreille were extensively burned and the forests have here been re-

placed in great measure by a cumbrous growth of brush. The valley of Mooyie River from the boundary to its mouth has suffered more recently. At the time my party passed through it in 1905 there were to be seen only a few forlorn remnants of a once continuous forest, and even these were in course of destruction. To the east of this valley, however, in the drainage of its tributaries and those of the Yaak, is one of the largest areas of virgin forest in the region. From the higher points of the Yaak-Kootenai divide a broad expanse of forest-clothed ridges extends on every side. The timber of this area, however, is the least marketable in the entire region, and its greatest value to future generations must probably consist in the shelter it affords to game and fur-bearing animals and its efficiency in conserving the rainfall of a great part of the Kootenai drainage basin. At the present time it constitutes part of the Kootenai National Forest.

INDUSTRIES.

In spite of comparatively good railway facilities, the mountainous region with which this report is concerned has but a sparse population. The people are occupied with agriculture, lumbering, and mining, but none of these industries is being pursued very extensively or systematically.

Lumbering supports large sawmills at Sandpoint, Bonners Ferry, and other points on Clark Fork, but an abandoned mill, once operated by power from Thompson Falls, bears witness to a decline in this line of activity.

Agriculture is pursued to some extent on the terraces of the larger valleys. The most desirable farm sites seem to be on old delta fans at the mouths of tributary canyons, where the soil is richer than on the sands and gravels of the rivers. The crops consist chiefly of hay and apples, but in places grains and small fruits thrive.

The mining industry of this region, regarded as a whole, is probably not at present self-supporting. The profits from the one mine steadily producing at the time of this reconnaissance are presumably far overbalanced by the labor being spent by prospectors with no immediate, and in many cases no prospective, results. But the fortunes of the mining population are doubtless taking an upward turn. The high hopes generated years ago by the finding of rich oxidized ores near the surface gave way, when these bonanzas were exhausted and there remained only lean sulphides, to a state of discouragement, from which a healthy reaction is now setting in. The renewal of activity, guided by conservative principles, which is now taking place, gives reason to hope that mining in this region will before many years be put on a firm and profitable basis.

A brief discussion of the mineral resources and mining development will be found in a subsequent part of this report (pp. 92–108).

ROUTES OF TRAVEL.

Taking advantage of the relatively small width of the mountain zone at the north, and of the existence of a number of low-grade valleys whose course is more or less transverse to the trend of this zone, three important railways, uniting at Spokane, cross the region here described within about a hundred miles of the international boundary. The northernmost of these is the Great Northern Railway, the one next south the main line of the Northern Pacific, and the southernmost one the route connecting the Cœur d'Alene district with Spokane on the west and with Missoula on the east. The portion of the last-named route that extends from Wallace to Missoula is owned by the Northern Pacific Railway Company, and the portion west of Wallace by the Oregon Railroad and Navigation Company.[a] Between this route and the Oregon Short Line, some 250 miles farther south, there lies a broad expanse of wooded mountains dissected by profound and narrow valleys which do not appear to afford any practicable passage for a transcontinental railway. Two subsidiary railway lines, joining the Great Northern at Bonners Ferry, extend into Canadian territory, one following the Purcell trench, and the other the valley of Moovie River. It helps one to realize the geographic importance of the Purcell trench to note that it is continuously occupied by railroads from Rathdrum Prairie northward beyond the international boundary.

These numerous railways make the sparsely settled Idaho "panhandle" and the neighboring portion of Montana comparatively easy of access. Most of the principal wagon roads follow the railway lines. The Northern Pacific is paralleled by tolerable roads for the entire length of its course across the region. The main line of the Great Northern, however, can not be followed with a wagon. A road extends from Bonners Ferry to Troy, making a long detour toward Sylvanite to avoid the ravines that notch the edge of the high terrace north of the river. The gorge between Troy and Libby, however, is traversed only by the railroad and a very precarious trail on the north side of the river. East of Libby, also, there is no wagon road along this railway. A wagon road follows the Cœur d'Alene route from Missoula to Mission, in Cœur d'Alene Valley, but there it diverges to the north and reaches the town of Cœur d'Alene by way of Fourth of July Canyon. This portion of the route is so rugged as to be almost impracticable for heavy vehicles. The portion of the road

[a] Since the writing of this report the last-mentioned route has been adopted for the transcontinental line of the Chicago, Milwaukee and St. Paul Railway, now under construction. The Northern Pacific Railway Company, abandoning the tracks between Missoula and the mouth of Flathead River, which formerly were part of its main line, has constructed a roadway through the gorge of Missoula River from St. Regis to its mouth, and will henceforth send its transcontinental traffic along that stream, thus avoiding the steep grades that formerly had to be traversed between Missoula and Jocko.

near St. Regis Pass is likewise difficult of passage for any but a very light wagon. The Purcell trench is followed by good roads from Lake Cœur d'Alene to the international boundary.

In addition to these main wagon routes there are subsidiary ones which cross or penetrate the mountain ranges. The Mooyie Valley Railway is to be followed by a wagon road, which was in course of construction at the time of our visit. The Cabinet Range is crossed by a fairly good road over the low Bull Lake Pass. This route, however, is debarred by Clark Fork from approach by wagons from the south. A second route across the range follows a wagon road up Vermilion Creek and its west fork to the Silver Butte mine, and thence by a very poor trail which connects with other wagon roads among the eastern foothills of the range. After crossing the divide on this trail, one reaches wagon roads within a few miles which lead to Libby by way of Swamp Creek and the lower part of the well-made road to the Snowshoe mine. The Cœur d'Alene Range may be crossed by a wagon road from Thompson Falls which follows Prospect Creek to its headwaters and then gives a choice between two routes into the Cœur d'Alene district—the one a very rough and steep-graded route by way of Glidden Pass and Burke, the other a longer but easier route by way of Thompson Pass and Mullan.

The wilder parts of this region are not to be reached by wagon roads. Numerous pack trails traverse it, however, and almost any portion of it may be reached by a day's walk from a point accessible to horses. It is impossible to enumerate all the minor trails in this region that lead to active or abandoned mining properties, but some of the more important routes that are practicable for pack horses may be mentioned.

The international boundary between Porthill and Gateway may be followed in a general way, though not closely, by the route used by the boundary commission in setting the monuments that mark the position of the forty-ninth parallel. The route from the Purcell trench to Round Prairie, at the edge of Mooyie Valley, is a wagon road that follows a short flat-bottomed trench that cuts through the mountain ridge between the two meridional valleys. By this time this wagon road will doubtless have been extended to Spokane Junction, on the Canadian Pacific Railway. Thence a trail leads up Hawkins or Meadow Creek and over a very low pass into the basin of Yaak River, following the west fork of that stream to the point where it bends abruptly southward and crosses the boundary. From this portion of the main trail, which lies a few miles north of the forty-ninth parallel, there are several short branch trails to boundary monuments. The portion of the trail east of the west fork of Yaak River was made for the boundary commission, and follows the boundary as closely as the conformation of the ground permits.

The basin of Yaak River is reached from the south by a trail from Libby, which follows Pipe Creek to the head of the south fork, whose valley it follows down to the main stream. The trunk of the river is followed by trails from the boundary route to Sylvanite. The route upstream from the South Fork we found to be confused by frequent branchings, and in places obstructed by windfalls of lodgepole pine, and the downstream trail, not followed by my party, has an ill name among the few inhabitants of the region.

The mountains between Mooyie and Yaak rivers are probably more accessible from the south than from the north, although the party did not attack them from that direction. But the road to the Buckhorn mine leads to their crest, and the late R. U. Goode[a] states that Mount Ewing, about 10 miles south of the boundary, was reached by pack horses from that mine.

The Cabinet Range has few trails of importance, but its western part is penetrated by some prospectors' trails, and many of its level and sparsely wooded ridges might be followed on horseback for considerable distances, so that there would be no serious obstacles to thorough exploration of that portion of the range. The rugged area east of Bull Lake Valley would offer more serious difficulties, but by means of trails extending up several of the creeks on the east side a large part of its crest could be examined without often resorting to man power for carrying camp equipage. The journey to Bear Peak and return was accomplished in a day from a camp several miles north of the Snowshoe mine, notwithstanding that several hours were spent beside the Lake of Shadows in waiting for fog to lift from the summit.

The northern part of the Cœur d'Alene Mountains is traversed by several trails in more or less imperfect states of repair. The best of these is the Leiberg trail, named for its maker, Mr. John A. Leiberg, who has prospected extensively in the basin of the Little North Fork. It follows the Little North Fork of Cœur d'Alene River to its head, then after crossing Chilco Mountain descends to the plain near the southwest end of Lake Pend Oreille. This trail, originally made with great care, is still occasionally used, although not kept clear of windfalls. The crest south of Lakeview, a little farther east, is reached by wagon road, and thence another trail leads over the hills to the main North Fork of Cœur d'Alene River. Its condition, except for its northernmost part, is not known, and its usefulness is limited by the necessity of ferrying from Lakeview to the opposite shores of the lake. The Cœur d'Alene district, in the early days when the placers on Eagle and Prichard creeks were its main

[a] Survey of the boundary line between Idaho and Montana from the international boundary to the crest of the Bitterroot Mountains; Bull. U. S. Geol. Survey No. 170, 1900, p. 38.

attraction, was reached by a trail from Clark Fork which followed Trout Creek and the ridge between the forks of Eagle Creek, but this route has fallen almost entirely out of use. Passage from the Clark Fork–Flathead Valley to the valley of the stream generally known as Missoula River may be effected in two ways. The more direct route is a trail, whose condition is not known, that leads from Plains to St. Regis. The other is by way of Paradise Springs and the Iron Mountain mine. This route, which I traversed, follows a wagon road from Plains to the springs. The passage of this portion necessitates ferrying first Clark Fork below the Flathead and then the river known locally as the Missoula. From Paradise Springs one follows a trail until it reaches, a short distance north of the divide, the road formerly used for hauling the ores of the Iron Mountain mine to a point on Missoula River some miles above the springs. This road leads to the town of Superior, on the Cœur d'Alene branch of the Northern Pacific Railway. The gorge of Missoula River between the mouths of Flathead and St. Regis rivers is too narrow to have been adopted as a route of travel even by Indians.

SETTLEMENTS.

Except in the immediate vicinity of the railroads, the population of the region is extremely sparse. Some families make their homes on small ranches in the valleys; at the few producing mines there are groups of buildings occupied by those engaged in the work of exploitation, and there are several lumber camps among the wooded hills; but the less accessible parts of the mountains contain only the scattered habitations of lonely prospectors and of the fewer and still more solitary hunters that find subsistence in the wilderness. The greater part of the inhabitants of the region are gathered into settlements on the railways, and of these settlements only a few are worthy of especial mention.

On the Great Northern Railway the only considerable towns that lie within our field are Bonners Ferry, Troy, and Libby. Bonners Ferry, with a present population of about 700, bids fair to increase in importance with the completion of the Mooyie Valley Railroad, which will make it a junction point of some importance. Both Troy and Libby, which are farther east, have suffered considerable loss of population in late years, having reached their maximum prosperity at the time the railroad was in course of construction. Their future development must depend chiefly on the development of the mines in their vicinity. In the valley of Yaak River Sylvanite, a town once occupied by several hundred inhabitants, presents a scene of desolation that is typical of abandoned mining camps.

Of the towns on the main line of the Northern Pacific, Sandpoint, which also has a station on the Great Northern, is the most flourish-

ing and gives most promise of future growth. Its population is about 1,500. Its most substantial industry at present is lumbering. If, however, the recent establishment of a smelter in the neighborhood has the stimulating effect upon ore production about the shores of Lake Pend Oreille that may reasonably be hoped, a considerable accession to the wealth and population of this town may be expected. The agricultural possibilities of the vicinity are doubtless capable of considerable development, for its loamy soil appears well adapted to those fruits and vegetables for which the climate is not too cold. The nearest important settlement to the east is Hope, until recently a division point on the railroad, but now supplanted in that function by Trout Creek. Still farther east lies Thompson Falls, a small town dependent on agriculture and undeveloped mines, apparently not actively progressing in importance, and Plains, whose prosperity, evidenced by many new buildings and an appearance of activity, depends chiefly upon stock raising.

South of the main line of the Northern Pacific the most important town in the region, exclusive of the Cœur d'Alene mining district, is Cœur d'Alene. Like Sandpoint, it derives its chief support from lumbering, but this source of revenue is largely supplemented by agriculture and by the numerous seekers after rest and recreation who resort to it in summer.

East of the Cœur d'Alene district the valleys of the St. Regis and the Missoula contain several small towns of no great importance at the present time. Their dependence is chiefly on the lumbering industry, and to a less extent on mining.

CHAPTER II.

GENERAL SUMMARY OF THE GEOLOGY.

PRELIMINARY OUTLINE.

That mountainous portion of northern Idaho and northwestern Montana described in the preceding pages which lies east of the Purcell trench is now known to form part of one of the largest areas of Algonkian rocks in North America. Along the forty-ninth parallel these ancient sediments occupy the surface almost continuously from the eastern front of the Rockies to the Purcell trench, which for a great part of its length forms the boundary between these distinctly bedded and but slightly altered strata and an assemblage of schistose and massive rocks strikingly contrasted with them in appearance. The extent of the Algonkian tract northward is not yet known very definitely. In its eastern part, at least, it becomes largely interspersed with areas of later rocks within a relatively short distance from the international boundary. At the south it narrows abruptly near the forty-seventh parallel, where it is deeply cut into at the west by a great body of granular intrusive rock. Its southward continuation at the east becomes more and more broken and it is finally quite replaced by younger sediments and igneous intrusives. The region here described lies therefore almost entirely within an extensive tract occupied mainly by Algonkian sediments, but it includes areas of other rocks of several widely differing kinds.

The rocks west of the Purcell trench consist chiefly of granites, schists, and gneisses, in complex association. They comprise rocks that are partly of sedimentary origin, but mostly produced from intrusive igneous magmas, which have been rendered more or less schistose by pressure. The intrusive rocks in all probability represent several different periods of igneous activity. There are reasons, which will be detailed on subsequent pages, for believing that most of the gneiss and granite occurring on the west side of the Purcell trench, north of Clark Fork at least, was intruded after the accumulation of the Belt series. But south of that stream, and especially in the vicinity of the town of Cœur d'Alene, there are exposures of rocks far more intensely deformed, which may be of Archean age, although the evidence on that point is not conclusive.

The Belt series, whose areal distribution is limited on the west by the Purcell trench along the greater part of the course of that depression through the region here considered, consists of an enormous thickness of distinctly bedded sediments, which, in strong contrast to the rocks mentioned above, do not in general betray conspicuous evidence of alteration. The Belt rocks are chiefly sandstone and shale, or their slightly altered equivalents, quartzites, and hard argillites, but they include also a moderate amount of impure limestone and dolomite containing considerable iron carbonate and silica. The striking characteristics of the series as a whole are its enormous thickness of more than 30,000 feet, its essential conformability throughout, the abundant evidence that the greater part of it was laid down in extremely shallow water, and the fine texture of its constituent materials, which comprise almost no conglomerates.

Folded and faulted into these pre-Cambrian sediments, and very subordinate to them in aggregate surficial area, are several masses of supposedly Paleozoic rocks. The belief that they are Paleozoic rests partly on the finding of a few obscure fossils on Swamp Creek and near Lothrop, and partly on the following lithologic evidence. All these masses consist in large part of relatively pure and thick-bedded limestone. Such material makes up the greater part of the well-known Paleozoic sections of central and western Montana, and differs from the limestones known to belong to the Belt series, which are generally thin bedded and largely admixed with silica and the carbonates of magnesia and iron. It is wholly on this lithologic evidence that certain limestone masses in which no fossils were found, notably those near the south end of Lake Pend Oreille, are considered as probably Paleozoic.

The Algonkian sediments, as well as the limestones near Lake Pend Oreille, have been invaded by great masses of igneous magma, which differ from one another in composition and mode of occurrence. The most extensive of these intrusions are irregular batholithic masses of acidic igneous rocks, which occur for the most part in the western part of the region, and with these it is believed that a large part of the great mass of granitoid rock west of the Purcell trench is contemporaneous. In addition to these batholiths there are masses of more basic rocks, injected for the most part between the strata, but partly into fissures transverse to the bedding.

These intrusions were probably in part contemporaneous with the extensive deformation which the region has undergone. In general, the rocks do not show intense folding except in the southern part of the region, where the structure is more complex than in the northern part. The most conspicuous tectonic features of the region are a number of great faults, some of which are remarkable for their persistence and the magnitude of their throw.

Owing to the almost complete absence from this region of stratified rocks younger than the early Paleozoic, a great part of the geologic record is missing. One can only conjecture whether these rocks were never deposited there, or whether they were deposited and later removed by erosion. The date of the intrusion and deformation which the region has suffered is likewise a matter of conjecture, which may range unchecked by definite facts through a great stretch of geologic time. Nor can we attempt to judge closely at what period the region was finally exposed to those erosional activities which gave the land surface its present form.

It is certain, however, that the origin of some of its topographic features must be referred back to the early Tertiary. The most definite reason for so doing is the relation of the basalt of the Columbia Plain to the older formations. The Columbia Plain is underlain by basalt whose flows lie for the most part in a nearly horizontal attitude and, in the vicinity of Spokane, abut against the gentle slopes of the hills to the east, which are carved in the ancient schists and granites. In the valley of Spokane River one may see terraces of basalt at the bases of the slopes on either side, and the same features may be seen in still more conspicuous development about the shores of Lake Cœur d'Alene and in the lower part of the valley of Cœur d'Alene River. The presence of the terraces makes it clear that these depressions had attained something like their present depth before the period of basaltic eruption, which, as investigations in other regions have shown, was in Miocene time.

The inundation with basalt of the lower portions of these valleys and that of Clark Fork must have had some notable influence on their subsequent development and that of their tributaries. The effect of the retardation of the down cutting of the streams is believed to be shown in the presence of rock-cut benches several hundred feet above the present water level in all the major valleys of the region.

Another formation, probably of Neocene age, whose relation to the basalt has not been directly observed, occurs only in the eastern part of the region and was seen near Plains, in the broad part of the valley of Flathead River, and in the vicinity of Missoula. It consists of very light-colored, soft, fine-grained rocks, with obscure bedding generally in an almost horizontal attitude. The material was not collected or closely examined in this reconnaissance, but it is doubtless identical in part with that which has received much attention from Rowe[a] and Douglass[b] and which occurs very extensively in the intermontane valleys of western and central Montana. It is perhaps

[a] Rowe, J. P., Some volcanic-ash beds of Montana: Bull. Montana Univ. No. 17, 1894.

[b] Douglass, Earl, The Neocene lake beds of western Montana and descriptions of some new vertebrates from the Loup Fork: Bull. Montana Univ., 1899; New vertebrates from the Montana Tertiary: Carnegie Mus. Ann., vol. 2, pp. 145–199; Am. Jour. Sci., 4th ser., vol. 10, 1900, p. 428.

equivalent also to the Bozeman lake beds of the early Montana folios.[a] These rocks also occur and have been observed by me in the Philipsburg quadrangle. The material from the last-named vicinity proved when examined microscopically to be of volcanic ash. Rowe,[b] however, had previously shown that this was true, and that all the material which he studied, including some that occurs within the area considered in this bulletin, was of similar character. The beds near Missoula contain fine impressions of fossil leaves, figured in Rowe's paper, which prove their Neocene age.

The conditions under which these beds were laid down are imperfectly known and need not be discussed here. It is well to remark in passing that the assumption, formerly so often made, that extensive deposits of fine-grained, more or less definitely stratified clastic material must necessarily be of lacustrine origin, is especially lacking in justification when the deposits consist of volcanic ash. It is probable that in general volcanic-ash beds accumulate in great part on dry land, but that as their accumulation is relatively rapid, they may readily cause the rapid shifting of streams and the ponding of drainage. The latter effect is likely to be produced also by eruptions of lava closer to the volcanic centers.

The interpretation of the land forms produced by post-Neocene erosive and depositional agencies constitutes by no means the least interesting of the problems to be solved when the region is subjected to thorough geologic study. These problems were apart from the principal objects of the reconnaissance and received but little attention during its progress, but brief mention of some of the more striking features of the physiography and surface geology may serve to bring into notice a most attractive field for investigation by students of such matters.

The general approximation to a common level exhibited by the mountain ridges of large portions of this region has been remarked by Lindgren[c] and by Daly.[d] This condition still awaits a thoroughly worked out and satisfactory explanation. Lindgren inclines to the belief that the southern part of the region is a dissected peneplain, while Daly, on the basis of observations in this and other regions, has constructed an argument against the too broad application of the peneplain theory by showing that the topography generally thought characteristic of an elevated and maturely dissected peneplain can be formed in other ways; that in fact it tends to be formed in any mountain region at no very advanced stage of topographic development.

[a] Peale, A. C., Three Forks folio (No. 24), Geol. Atlas U. S., U. S. Geol. Survey, 1896; Weed, W. H., Livingston folio (No. 1), Geol. Atlas U. S., U. S. Geol. Survey, 1894.

[b] Op. cit.

[c] Prof. Paper U. S. Geol. Survey No. 27, 1904, p. 59.

[d] Geol. Survey Canada, Summary rept. for 1904, p. 94; Jour. Geology, vol. 13, 1905, p. 105.

Very high rock-cut terraces, observed in particular along Clark Fork, west of Bull River, may aid in the interpretation of the early drainage history. The possible connection of one with the Tertiary basalt floods has already been mentioned.

The more striking of the younger physiographic features are those due to ice action. As shown by Chamberlin,[a] though without indication of the basis of his conclusions, the northern part of the region was mantled by the Cordilleran ice sheet, which sent a lobe down the Purcell trench at least as far as the southwest end of Lake Pend Oreille and there attained its greatest extension toward the south. The map in Chamberlin's report should be amended to show the valley of Clark Fork as occupied by ice from north of Bull River to Lake Pend Oreille, for strong indications of glaciation by a deep ice stream appear on the valley bottom between these places and for several hundred feet up its sides.

Daly[b] has noted that the limit of general glaciation was at 7,300 feet above sea level at summits occurring in the middle of the Purcell Range on the forty-ninth parallel. On the slope north of Hope glaciation has been effective up to a level of about 2,500 feet above the lake, or about 3,500 feet above sea level. The striæ run nearly north and south. At the mouth of Bull River erratic bowlders were noted at a level of 2,000 feet above Clark Fork.

The hills lying south of the outlet of Lake Pend Oreille exhibit a highly typical effect of ice erosion. They are carved from sandstones and shales of the oldest portion of the Belt series with a regular strike not far from north-south. Viewed from a distance, their sides appear to have a rude horizontal fluting on a huge scale, owing to the projection of the more resistant strata, whose edges are gently rounded off. While these projecting ledges are almost barren, the intervening terraces which mark the position of the softer beds are covered more or less thickly with brush. The impossibility of such features being produced by water erosion is obvious. Similar sculpture was noted in other places, notably along Swamp Creek, and others were seen along Clark Fork southeast of Hope and elsewhere. "Roches moutonnées" in the trench west of these hills have been figured by Chamberlin.[c]

As already hinted, a noteworthy physiographic peculiarity of the region is the existence of numerous flat-bottomed valleys, long in proportion to their width, many of which are divided by very low watersheds, whence the streams draining the depressions flow in opposite directions. The Purcell trench exemplifies these features typically and on a grand scale; other examples are the Bull Lake trench and

[a] Chamberlin, T. C., Seventh Ann. Rept. U. S. Geol. Survey, 1888, Pl. VIII, pp. 178–179, and fig. 15.

[b] Geol. Survey Canada, Summary rept. for 1904, p. 95.

[c] Op. cit., fig. 15.

the one that cuts so deeply into the ridge dividing the Mooyie from Kootenai River. Another seems to lie across the head of the Cabinet Range at the head of Thompson River. It is probable that these depressions, even though their location may have been determined primarily in many cases by fault lines, have been brought to their present form by the long-continued erosion of great valley glaciers, powerful enough to override the divides between the heads of some of the larger streams and to grind them down nearly to the general base-level. The conditions indicated especially characterized the period following the retreat of the continuous ice mantle and are those now prevailing over large portions of Alaska.

Typical morainal deposits are not so abundant in this region as the great extent of its glaciation might lead one to expect. Indeed, a comparison with certain parts of west-central Montana, where, possibly because the postglacial climate has been more arid, moraines are far more abundant and better preserved, indicates that in the area with which we are here concerned the glacial deposits have been very largely rearranged by water. No continuous lateral moraines were noted. The terminal moraine of the ice lobe that came down the Purcell trench is not a conspicuous topographic feature. The dam of the southwestern arm of Lake Pend Oreille has a steep slope toward the water and is composed of material which may be perceived to be of glacial origin from an examination of the good exposures on the wave-worn sides of the little cape at Steamboat Landing. Here may be seen an ill-assorted mixture of subangular bowlders as much as 3 feet in diameter with material grading downward in size to fine sand. The surface to the westward, however, although not without many shallow undrained hollows, appears as if smoothed over to a certain extent by flowing water.

Great quantities of glacio-fluviatile gravels composed of products of ice abrasion have evidently been spread out by voluminous heavy-laden streams beyond the area of ice invasion. Such gravels form the dam of Lake Cœur d'Alene and of many other lakes already mentioned which are similarly retained in small valleys just above their junction with much larger ones.

In the vicinity of Bonners Ferry there were seen exposures of a very extensive deposit of fine-grained light-colored sands and silts, which form a high and broad terrace. These could hardly have been precipitated from suspension except in still water or a very sluggishly moving current. It seems probable, therefore, that they were accumulated in a lake formed in the Purcell trench during the recession of the ice, held in at the south by the terminal moraine and on the north by the glacier front. Abundant fine sediment would have been rapidly supplied by the milky waters that flowed from the dwindling glaciers.

In the following section of this paper a description of the bedrock formations, with the exception of the ash beds, will be given. Further consideration of the physiography and surficial deposits will be omitted, for although the region offers a most attractive field for special students of such features the cursory nature of my observations relating to them makes it unjustifiable to enter into a full discussion of the surface geology, some of whose more noteworthy features have just been indicated.

The geologic sketch map which forms Plate I exhibits rudely the areal distribution of the principal geologic terranes of the region and the larger features of the structure, so far as these have been ascertained. Its purpose is to aid in the understanding of the descriptive text, and it makes no claim to detailed accuracy. In particular the boundaries of the small areas of intrusive rocks, of Paleozoic strata, and of Miocene basalt have only diagrammatic value, being intended to show the approximate position of the masses actually seen.

STRATIGRAPHY.

ANCIENT SCHISTS AND GNEISSES.

The highly altered rocks, which are considered as probably older than the Belt series, have been observed chiefly about the northwest arm of Cœur d'Alene Lake and along the valley of Spokane River. A few minor occurrences of rocks more doubtfully referable to the Archean were noted along Clark Fork. These metamorphic rocks comprise a variety of schists and gneisses which are in part certainly of igneous origin, while a part have the appearance of metamorphosed sediments. As these rocks have not been sufficiently studied to render possible a satisfactory general description of them, only a brief indication of their general character in the principal outcrops observed will be given. After this has been done an attempt will be made to summarize the evidence that has been gathered in our field regarding their age.

One of the best exposures is found in a cutting for the electric railway at Post Falls, on Spokane River. This displays greatly sheared granular igneous rocks, varying somewhat in texture and composition, cut by dikes of aplite and pegmatite. The granular rocks are composed essentially of plagioclase and orthoclase, abundant quartz, and considerable biotite and muscovite. The two feldspars are present in amounts not far from equal, except in a local phase in which plagioclase predominates over orthoclase. Farther east along Spokane Valley and south of the river there are exposures of granite and of a gneiss thought to be of sedimentary origin, but cut by dikes and sheets of clearly intrusive granitic rock. The sup-

posedly sedimentary gneiss is fine grained and of a light-gray color, is composed essentially of quartz, feldspar, and mica, and has a distinct foliation, brought out by parallel arrangement of the biotite flakes. The laminæ, though somewhat crumpled, have a low general dip. The gneiss is cut by numerous dikes and sheets of pegmatite and medium-grained granitic rock. Examined microscopically the foliated rock is found to have quartz as its chief constituent, but it contains a large proportion of feldspar, chiefly orthoclase. The micas are not very abundant.

Just south of the town of Cœur d'Alene is a small hill of fine-grained highly schistose gneiss, rich in muscovite, cut by dikes of pegmatite, which have also been sheared.

Excellent exposures of the ancient-looking crystallines are found in a quarry at Threemile Point, about 3 miles south of Cœur d'Alene, on the western shore of the lake. The rock here consists mainly of fine-grained, light-gray banded gneiss, like the supposedly sedimentary gneiss of Spokane Valley. It has a remarkably regular cleavage, which dips gently south and breaks readily into smooth, flat slabs. This is cut by many dikes of pegmatite which have evidently suffered considerable shearing, and a narrow dike of fine-grained granitic rock which is not distinctly laminated. Some greenish-black hornblende schist containing garnets was found here, but its relations to the other rocks were not made out. From its composition, as seen under the microscope, it may have been derived from diabase or a related rock.

On Clark Fork a short distance above Laclede there was seen some banded schist intruded by a porphyritic granite or monzonite, and on the south side in the same vicinity is exposed an augen gneiss rich in hornblende, which is probably a sheared diorite.

The problem of the age of these rocks is far from being definitely solved. Daly,[a] from evidence still to be given in detail, believes that on the forty-ninth parallel west of the Purcell trench there are rocks much older than the Belt series. The evidence to be presented here relates solely to the rocks west of Lake Cœur d'Alene, with which I am acquainted. That these are partly Archean and much older than the Belt series is the suggestion that is most naturally brought to mind by the salient features of their character and occurrence. The fact that the schistose parts of the complex everywhere display far greater metamorphism than the Belt rocks east of the Purcell trench show, except, perhaps, very locally and in immediate proximity to large batholiths; the sharp discontinuity between this complex and the relatively little altered sediments; the fact that the Belt rocks more commonly than otherwise dip away from the boundary be-

[a] Geol. Survey Canada, Summary Rept. for 1903, p. 97.

tween the two terranes—all are consonant with the supposition that the highly schistose rocks form a basement upon which the Belt sediments once rested with strong unconformity.

But the alternative possibilities pointed out by Ransome[a] are worthy of consideration. It is possible that these rocks are Algonkian or post-Algonkian; that their high degree of metamorphism is due to igneous intrusions by which they have been so thoroughly penetrated; and that their present position is due to faulting along the line of the Purcell trench, either contemporaneous with or subsequent to the intrusion, with downthrow to the west. In some degree confirmatory of this hypothesis is the fact that obscure traces of what appear to be Paleozoic corals have been found in crystalline limestone apparently forming part of this complex not far north of Spokane.[b] Again, some of the intrusive rocks entering into the crystalline complex are certainly younger than the Belt series. The coarsely porphyritic granite (see p. 44), extensively developed west of the Purcell trench near Sandpoint and to the north, occurs also on the east side, where it is in irruptive contact with the Belt rocks.

Personally I am inclined to the belief that some of the rocks described in the preceding paragraphs are older than the Belt, but the contrary belief is certainly not excluded by the evidence now available. The problem is doubtless capable of solution, but it will be solved only by patient and thorough work.

ALGONKIAN ROCKS.

GENERAL STATEMENT.

It is proposed to give here a brief generalized description of the Algonkian section, which will apply to the whole region. Many details, especially regarding the upper, less-known strata, will be left for description in Chapter III, which will be devoted to the areal geology of the region reconnoitered in 1905; and in the report on the geology of the Cœur d'Alene district[c] a detailed description of the formations that occur in that district may be found.

PRICHARD FORMATION.

The lowest portion of the Belt series in this region consists of an assemblage of bluish argillites, grayish quartzite, and rock intermediate in character between these. For the purposes of this paper this assemblage of strata is considered as a stratigraphic unit. It will be

[a] Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908, p. 18.

[b] Shedd, Solon, Building and ornamental stones of Washington: Rept. Washington Geol. Survey, vol. 2, 1903, pp. 84–85.

[c] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908.

referred to as the Prichard formation, because it is considered essentially equivalent to the Prichard slate, whose type locality is the basin of Prichard Creek in the Cœur d'Alene district. It may include beds contemporaneous with part of the Neihart quartzite. The base of the Prichard has not been seen in the area of this reconnaissance. Its upper limit is fairly well defined and is marked by a lithologic change from the blue argillites that everywhere form the uppermost part of the Prichard to the greenish-gray, flaggy, siliceous sediments that form the base of the overlying Ravalli group.

The Prichard formation varies considerably within the limits of the region. In the Cœur d'Alene district it consists chiefly of dark gray-blue, regularly banded argillite or slate, with a subordinate amount of interbedded gray sandstone, which is apparently not more abundant in the lower than in the upper part. In the extensive exposures near Plains, Paradise Spring, and Dixon, east of the Cœur d'Alene district, the lithologic character of the formation is essentially the same as at the type locality. The same may be said of the area crossed by Vermilion Creek, northeast of the Cœur d'Alene district, but here it is probable that erosion has not cut so far down into the formation. However, in going westward from Wallace to the town of Cœur d'Alene, a gradual change in the prevailing character of the Prichard rocks was observed. They become, on the average, a little more silicious and coarser toward the west. Subsequent study of the sections about Lake Pend Oreille, along Kootenai and Yaak rivers, east of Bonners Ferry, and in the vicinity of the forty-ninth parallel showed that a similar change proceeds to a still more marked degree toward the north. In the western part of the Cabinet Range the formation consists in greater part of gray quartzitic sandstone, with which, however, considerable argillaceous material is interbedded. Along the international boundary the siliceous character of the formation is even more marked, and it is there represented, wholly or in large part, by Daly's Creston quartzite. But, as I have already indicated, the uppermost part of the formation is everywhere argillaceous. In the excellent exposures just west of Scotchman Peak, in the Cabinet Range, the Ravalli group is immediately underlain by about 2,000 feet of rock which closely resembles the typical Prichard slate of the Cœur d'Alene district. On Callahan Creek, on Kootenai River near Lenia, and near Sylvanite on Yaak River, similar rocks were seen at the same horizon, developed to a thickness amounting at least to several hundred feet, although nowhere closely estimated. Near Spokane Junction, a few miles east-northeast of the point where Mooyie River crosses the boundary, similar rocks were seen, underlying greenish and purplish beds supposedly belonging to the Ravalli group.

It will be understood from what has been said that the correlation of all the strata below the Ravalli with the Prichard involves the hypothesis that all but the uppermost part of the formation gradually changes in character along the strike, so as to become more and more siliceous toward the west and north. The alternative hypotheses would be (1) that there is an upper argillaceous formation overlapping unconformably a lower siliceous formation and gradually thinning toward the northwest, and (2) that there is an unconformity of the base of the Ravalli. Neither of these hypotheses is supported by the field evidence, which appears rather to indicate that the Belt rocks of this area are conformable throughout.

The thickness of the group is roughly estimated at 10,000 to 15,000 feet. In the Cœur d'Alene district the Prichard slate is about 8,000 feet thick. The thickness of the beds exposed in the Cabinet Range would appear to be considerably greater, but they could not be reliably measured unless the structure were well worked out.

RAVALLI GROUP.

Overlying the Prichard formation is an assemblage of light-colored siliceous rocks varying from very pure white quartzite to siliceous shale. Much of the material is tinted in rather subdued tones of gray, green, purple, and red. In the Cœur d'Alene district this group comprises three distinct formations. These are, in ascending order, the Burke formation, consisting of grayish siliceous shales and sericitic quartzites; the Revett, of hard, white quartzite, and the St. Regis formation, consisting of purple and green siliceous shales and quartzitic sandstones. In the region north and east of the Cœur d'Alene district, however, the Revett quartzite is not everywhere present as a definite formation distinct in character from underlying and overlying portions of the group. It is typically developed in the Cabinet Range north of Heron, but over much of the region it is not distinctly recognizable, and, as the Burke and the St. Regis formations are not sharply differentiated from each other, the group can not be subdivided consistently on lithologic grounds. For this reason it is necessary to use a name that shall apply to all the rocks equivalent to the Burke, Revett, and St. Regis formations collectively. Ravalli group, Walcott's term for these rocks in the Swan Range section, appears the most suitable. The names of the subdivisions will be applied in the following pages to rocks that can be definitely referred to one or another of the formations recognized in the Cœur d'Alene district. The total thickness of the Ravalli group in the Cœur d'Alene district is about 4,200 feet. It increases, however, to the north and east. Daly estimates the thickness of the Kitchener quartzite of the section on the forty-ninth parallel, which may be equivalent to the Ravalli group, is about 7,000 feet, and Walcott gives about 8,000 feet

as the minimum thickness of the Ravalli "series" in the Mission Range where its base is not exposed. In the Cabinet Range, near Scotchman Peak, its thickness seems to be even greater.

NEWLAND FORMATION.

The quartzitic group is succeeded by a thick formation, distinguished from all those beneath by being in great part calcareous or dolomitic. This was called in the report on the Cœur d'Alene district the "Wallace" formation. In Walcott's Mission Range section its equivalent is the "Blackfoot limestone," and it is possibly to be correlated with Daly's Mooyie argillite. It is equivalent beyond reasonable doubt with the Newland limestone of the original Belt section, so that on grounds of priority it will be called Newland in the following pages. The formation is composed throughout of fine-grained thin-bedded rocks, which comprise green, more or less calcareous or dolomitic, sericitic slate, blue and white banded argillite, impure bluish or greenish ferruginous and dolomitic limestone, and light-gray white-weathering calcareous quartzite. All these types are connected with one another by gradations. The entire accumulation is characterized by sun cracks and ripple marks. In the Cœur d'Alene district the lowest part of this formation consists of green slate, overlain by a great thickness of thin-bedded argillite, impure limestones, and calcareous quartzites, in rapidly alternating succession. Higher in the formation the quartzitic beds are absent and the strata consist of impure limestones and argillites, the latter being partly made up of shale in very thin blue-gray and white layers and partly of gray-green, fairly homogeneous, somewhat calcareous argillite. Between these divisions the transitions are gradual, so that they are not mappable as distinct formations. The Newland formation was supposedly recognized throughout the region. Its general character is everywhere about the same as in the Cœur d'Alene district, but it apparently grows somewhat more calcareous eastward.

STRIPED PEAK FORMATION.

In the Cœur d'Alene district the Newland ("Wallace") formation is overlain by an accumulation of red and green argillite and quartzite with mud cracks and all other signs of shallow-water deposition. Its thickness is at least 1,000 feet in its best exposure on Striped Peak, from which the formation is named. The Striped Peak formation corresponds in lithologic character and position to the lowest part of the Camp Creek "series" in Walcott's Mission Range section. Beds similar to the typical Striped Peak and in the same relation to calcareous beds like the Newland ("Wallace") are found at intervals from the Cœur d'Alene district northward to the international bound-

ary, and would be correlated unhesitatingly with the Striped Peak if it were not that such a correlation would conflict with Daly's conclusions. As will be shown on a later page, he considers certain beds in the eastern part of the Purcell Range, which I believe equivalent to the Newland, as representing a calcareous phase of his Kitchener quartzite.

STRATA ABOVE STRIPED PEAK FORMATION.

Beds supposedly Algonkian and younger than the Striped Peak formation were found at various places in the northeastern part of the region, but their stratigraphy has not been thoroughly worked out, nor has their relation to the Striped Peak been absolutely demonstrated. These strata comprise a great thickness of dark greenish-gray argillites, with some thin beds of limestone, developed about Bear Peak in the Cabinet Range; green and purple argillites and quartzites, with a little limestone, of which a section is displayed in the gorge of Kootenai River between Troy and Libby; and gray and red argillites and limestones, with some quartzitic beds exposed in the Yaak drainage basin.

The Algonkian beds above the Newland, including those referred to the Striped Peak and those supposed to be younger, are probably roughly equivalent to Walcott's Camp Creek "series," although a definite correlation is hardly justifiable as yet.

These supposedly later Algonkian beds whose position in the stratigraphic column is not yet certain can not be treated systematically, but their local occurrences will be described in the section on "Areal geology" (see pp. 58 et seq.), with a view to aiding future work.

REGIONAL CORRELATION.

The accompanying table, based largely on that prepared by Walcott,[a] shows what seem to be the most probable correlations between the more complete sections of the Belt series that have been described. For some of the sections the correlation is based chiefly on a general similarity in the sequence of rocks. It is greatly strengthened in some cases by the presence of the characteristic fossil *Beltina danai* at a horizon near the top of the Newland formation, but even were this paleontologic evidence wanting, the lithologic evidence, discussed more fully in the report on the Cœur d'Alene district,[b] is, I believe, such as to leave little room for doubt concerning the essential correctness of most of the correlations. Those relating to the sections in the Mission Range, the Lewis and Livingston

[a] Bull. Geol. Soc. America, vol. 17, 1906, p. 18.
[b] Ransome, F. L., and Calkins, F. C., op. cit., pp. 25–28.

Probable correlation of principal sections of

Belt Mountains (Walcott).[a]	Lewis and Livingston ranges (Willis).[b]	Philipsburg district (Calkins).[c]	Mission Range (Walcott).[d]
Cambrian.	Top not seen.		Cambrian.
——Unconformity.——	*Kintla.* Shale, maroon red; ripple marks, etc.; some quartzitic and calcareous beds. 800 feet.		——Unconformity.——
Marsh. Shale, red, 800 feet.	*Sheppard.* Quartzite, yellow, ferruginous. 700 feet.	Cambrian.	*Camp Creek.* Sandstones, gray, rather thin bedded. 1,762 feet.
		——Unconformity.——	
Helena. Limestone, with some shale. 2,400 feet.	*Siyeh.* Limestone, dark blue or gray, weathering buff, with shale interbedded. 4,000 feet.	*Camp Creek.* Shale and sandstone, the latter prevailing in upper portion. Color chiefly red. 5,000+ feet to 0 feet.	Shales, sandstones, and limestones. 1,540 feet.
Empire. Shales, greenish gray. 600 feet.	*Grinnell.* Shale, partly arenaceous; dark red; ripple-marked and sun cracked. 1,800 feet.		Sandstones, mostly reddish. 4,491 feet.
Spokane. Shales, with thin beds of sandstone; deep red. 1,500 feet.	*Appekunny.* Shale, gray, black, and greenish, interbedded with white quartzite. 2,000± feet.		Sandstones, largely shaly, colors red and gray, with 198 feet of limestone 700 feet below top. 3,887 feet.
Greyson. Shales, mostly dark gray. 3,000 feet.			
Newland. Limestone, impure, weathering buff, with interbedded shale. 2,200 feet. *Beltina danai.*	*Altyn.* Limestone, upper part thin bedded and ferruginous; lower part grayish blue, massive, siliceous. 1,400 feet. *Beltina danai.*	*Newland.* Limestone, thin bedded, more or less siliceous and ferruginous, passing into shale; generally buff on weathered surface. 4,000 feet.	*Blackfoot.* Limestone, thin bedded, more or less siliceous; siliceous layers, weathering buff, interbedded with calcareo-arenaceous shales. 4,805 feet. *Beltina danai.*
	Base not exposed.		
Chamberlain. Shale, mostly black, with some sandstone. 1,500 feet.		*Ravalli.* Quartzite, gray, with some dark bluish and greenish shale. 2,000 feet.	*Ravalli.* Sandstones, quartzitic, fine grained, grayish purple and gray. 2,550 feet.
			Sandstones, compact, gray. 1,060 feet.
			Sandstones, greenish gray, fine grained, in layers 4 inches to 2 feet thick. 4,645 feet. Base not seen. Total Ravalli, 8,255 feet.
		Prichard. Shales, dark bluish, interbedded with sandstone; rusty brown on weathered surface. 5,000± feet.	
Neihart. Quartzite, with some shale in upper part. 700 feet.		Quartzite, light colored. Base not exposed. 1,000± feet.	
Archean.			

[a] Walcott, C. D., Pre-Cambrian fossiliferous formations: Bull. Geol. Soc. America, vol. 10, 1899, pp. 199–244.
[b] Willis, Bailey, Stratigraphy and structure, Lewis and Livingston ranges, Montana: Bull. Geol. Soc. America, vol. 13, 1902, pp. 305–352.
[c] Report in preparation.

Algonkian sediments in Montana and Idaho.

Cœur d'Alene district (Calkins).[e]	Cabinet Range, western and central parts (Calkins).	Forty-ninth parallel, between crossings of Kootenai River (Daly).[f]
Upper part of section eroded.	Shales and sandstones, medium to thin bedded; color prevailingly greenish gray, but in part red and purple. Shales partly calcareous and weathering buff. A little white crystalline limestone, weathering yellow, at several horizons. Base not seen. 10,000± feet.	Upper part of section eroded.
Striped Peak. Shales and sandstone, red and green. 1,000+ feet.	*Striped Peak.* Shales and shaly sandstones, prevailingly dark red; ripple marks, etc. 2,000+ feet.	*Yaak.* Quartzite. 500 feet.
Wallace. Shales, more or less calcareous, interbedded with thin layers of siliceous and ferruginous limestone and calcareous sandstone. Limestones and calcareous shales weather buff. 4,000 feet.	*Newland.* Limestones, thin bedded, siliceous and ferruginous, interbedded with more or less calcareous shales. 5,000± feet.	*Mooyie.* Argillite. 3,400 feet.
St. Regis. Shales and sandstones, purple and green. 1,000 feet.	*Ravalli.* Quartzites, siliceous shales, and shaly sandstones; upper part green and purple; lower part gray, mostly greenish, locally with faint purple tinge; middle part thickest bedded, and most quartzitic, consisting locally of fairly pure white quartzite. 8,000± feet.	*Kitchener.* Ferruginous quartzite. 7,400 feet.
Revett. White quartzite, partly sericitic. 1,200 feet.		
Burke. Indurated siliceous shales, with sandstones and quartzites, prevailingly gray-green. 2,000 feet.		
Prichard. Argillite, blue-gray to black, with distinct and regular banding, interbedded with a subordinate amount of gray sandstone. Uppermost part arenaceous and marked with shallow-water features. Base not exposed. 8,000+ feet.	*Prichard formation.* Argillite, dark bluish, banded. 2,000 feet. Sandstones, gray, thick bedded to shaly, interbedded with more or less sandy bluish shales. The rocks become more argillaceous toward the southeast. 10,000± feet. Base not exposed.	*Creston.* Quartzitic sandstones, thick-platy, gray, interbedded with a subordinate amount of bluish argillaceous material. Base not exposed. 9,500+ feet.

[d] Walcott, C. D., Algonkian formations of northwestern Montana: Bull. Geol. Soc. America, vol. 17, 1906, pp. 1–28.
[e] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908.
[f] Daly, R. A., Summary Rept. Geol. Survey Canada for 1904, 1905, pp. 91–100.

ranges, and the Belt Mountains, are supported by the weight of Walcott's authority, and the ground covered in my work in the Cœur d'Alene district and the Cabinet Range virtually joins with that covered by him. Although the Philipsburg work has not been joined with that of others, any correlation of the Philipsburg section essentially different from that shown in the table would involve the assumption that the formations change in character along the strike far more rapidly than they have yet been proved to do.

The correlation of the formations studied by Daly along the forty-ninth parallel is, however, distinctly tentative, and may be erroneous. Up to the present time only a very brief description of these formations has been published. The section given in the table is that which apparently indicates Daly's conception of the sequence in the western part only of the Purcell Mountains. Toward the east, according to him, the Creston and Kitchener quartzites become distinctly finer grained and are interleaved with calcareous material. It were hardly fitting that the impressions gathered in my hasty reconnaissance in the Purcell Mountains along the forty-ninth parallel should be opposed too positively to Daly's interpretation of the stratigraphy in the same area, based as it is upon more thorough work and perhaps fully supported by the detailed evidence which could not be presented in his brief preliminary report. But failing such evidence I find it difficult to believe that this marked change takes place within the distance of a few dozen miles, in view of what I have myself observed and in view of the resemblance between the different sections studied by others at widely separated points, especially when it is taken into account that several of these sections have been correlated on paleontologic evidence. My own belief, implied both in the preceding account of the stratigraphy and in the account of the areal geology that is to follow, is that the stratigraphic sequence in its larger features is essentially the same across the entire width of the area with which the present paper deals. The Newland formation, not recognized by Daly on the forty-ninth parallel except as a calcareous modification of strata that are not calcareous to the westward, is typically developed on the west side of Lake Pend Oreille, about 50 miles south of the international boundary.

SUPPOSED PALEOZOIC ROCKS.

Limestones are exposed on the southern shores of Lake Pend Oreille near Lakeview and on the north side of Squaw Bay. The conjecture that they are Paleozoic is suggested by their great lithologic difference from any calcareous rocks forming thick beds in any of the known Algonkian of this region. The limestone is gray to white in color. It is partly thin bedded, alternating in layers about an inch thick with thin laminæ of blue argillite, partly thick bedded;

and north of Squaw Bay, where it was doubtless affected by the neighboring intrusive granodiorite, it is massive and coarsely crystalline. The maximum thickness exposed in any one section is approximately 500 feet. In thickness and in lithologic character these limestones differ from the limy beds in the Newland formation as usually developed; the latter are generally to be measured in inches and are darker, harder, finer grained, and much less pure than the limestones on Lake Pend Oreille. In the northern part of the region limestone with some resemblance to those on Lake Pend Oreille occurs, but in beds only a few feet thick.

A heavy stratum of limestone is also exposed on Swamp Creek south of Libby. This rock is gray and thick bedded and contains forms that suggest worm borings. In the same vicinity is a series of gray and red shales with thin beds of pink limestone which contain a few imperfect molluscan fossils that to Dr. G. H. Girty, of the Geological Survey, had an Ordovician aspect.

Great bodies of gray limestones were also seen at various localities in the valley of Missoula River. This rock and its relations are best exposed in a hill on the north side of the river near Lothrop, where the thickness developed is about 1,500 feet. Its relations and character, in the opinion of Doctor Walcott, indicate that it is middle Cambrian.

IGNEOUS ROCKS.

GENERAL STATEMENT.

The igneous rocks comprise (1) acidic intrusives, which belong to the species quartz monzonite, granodiorite, and syenite; (2) basic intrusives, in dikes and sills, which comprise lamprophyre and diorite, the latter perhaps derived from the alteration of diabase and gabbro; and (3) volcanic rocks, including the altered basic lava interbedded with the Algonkian rocks east of Yaak River and the Miocene basalt.

ACIDIC INTRUSIVES.

QUARTZ MONZONITES.

General distribution.—Quartz monzonite occurs (1) north and east of Hayden Lake, (2) on Chilco Mountain at the head of the Little North Fork of Cœur d'Alene River, and (3) along the Purcell trench from Sandpoint northward.

Hayden Lake area.—The mass near Hayden Lake is of medium-grained, evenly granular, light-gray rock, whose essential constituents are quartz, plagioclase, orthoclase, microcline, and biotite. The plagioclase, belonging mostly to andesine, is about equal in amount to the alkali feldspar. Quartz is rather abundant, and biotite is present in moderate quantity.

Chilco Mountain area.—The rock forming the small area at the head of Little North Fork has the same essential constituents as the rock last described, but is more acidic. Biotite is rather scarce, and quartz in comparatively large anhedra is abundant. The most conspicuous megascopic feature is the porphyritic development of orthoclase, which forms phenocrysts not very thickly distributed that attain a length of about 1 inch. On microscopic examination the feldspars of the groundmass are found to be oligoclase and orthoclase, with the former in decided predominance. On the whole the two kinds of feldspar are apparently not very far from equal.

Areas along Purcell trench.—Along Clark Fork, from a short distance north of Laclede to Sandpoint, the country rock is a conspicuously porphyritic granolite. It shows rather abundant phenocrysts of orthoclase, mostly from one-half inch to 1½ inches long, in a groundmass that consists essentially of feldspar, quartz, and considerable biotite, which makes the rock somewhat darker than the one just described. Locally this rock exhibits a somewhat schistose structure, but this is far less pronounced than in the supposed Archean gneisses of Cœur d'Alene Lake and Spokane Valley.

Rock similar to this is found at Bonners Ferry, where it is strongly schistose. It crops out along the east side of the valley northward from that place for many miles, and in these outcrops the schistosity is not always marked. About 18 miles north of Bonners Ferry it was seen, from the train, in irruptive contact with siliceous sediments belonging to the Prichard formation. Near Naples, a small station on the Great Northern Railway about 12 miles south of Bonners Ferry, it is also found intrusive in the Algonkian. It is concluded, therefore, that the coarsely porphyritic granular rock exposed along the Purcell trench from Sandpoint to the vicinity of the forty-ninth parallel belongs to a great mass of post-Algonkian age.

Microscopic study of the groundmass of this rock shows an apparent predominance of plagioclase. Much of the feldspar shows faint zonal banding and very faint striation or none at all, so that there is some difficulty in distinguishing between the two feldspars. The classification of the rock as monzonite is made tentatively, but more thorough study might show it to be allied rather to the granites.

A related rock, probably of the same mass, forms a small knob that projects through the alluvium near Boyer, a small station east of Sandpoint. It contains not very abundant pinkish phenocrysts of orthoclase, having rather imperfect form and numerous inclusions, in a medium-grained granular groundmass which consists of plagioclase, orthoclase, considerable quartz, and some biotite and hornblende. In the groundmass the plagioclase predominates markedly over the orthoclase, but owing to the presence of the orthoclase phenocrysts the amounts of the two feldspars probably do not differ very greatly.

GRANODIORITE.

General distribution.—Granodiorite of a type that is widely distributed in the Pacific States, and familiar to students of the geology of the Sierra Nevada and the Cascade Range, forms a rather large intrusive mass that is exposed about the southern shores of Lake Pend Oreille, and there is an extensive area of granodiorite porphyry east of the lake.

Rocks differing from this widespread type of granodiorite, but coming within the class as originally defined by Lindgren, were observed at the west base of the Cabinet Mountains on the Northern Pacific Railway, on Lightning Creek, and east of Bull Lake. They are composed essentially of plagioclase, markedly subordinate alkali feldspar, quartz, and biotite.

Areas on Lake Pend Oreille.—The granodiorite in the areas about the southern shore of Lake Pend Oreille is clearly intrusive in the Newland rocks on Bernard Peak, and in the St. Regis formation just north of Cape Horn. The more northern of the igneous masses exposed on the eastern shore of the southern arm also is formed of the same rock.

The granodiorite of this vicinity is a rather light-gray medium-grained rock composed essentially of plagioclase, orthoclase, hornblende, biotite, and quartz, all of which may be distinguished by the unaided eye. It has no schistosity. The plagioclase, which forms crystals that are generally much clouded, belongs chiefly to oligoclase and andesine. It is much more abundant than the orthoclase, which is allotriomorphic against plagioclase and the ferromagnesian constituents. The hornblende, biotite, and quartz are present in moderate and nearly equal amount. Marginally, dark phases are developed in which the ferromagnesian constituents are more abundant than in the great bulk of the mass, which is highly uniform.

Closely related in mineralogical composition to this rock is a coarse-grained holocrystalline granodiorite porphyry, exposed for a short distance along the south shore of Pend Oreille Lake, and said to form Packsaddle Mountain, some miles eastward. Its outcrop at the lake shore is limited on both sides by faults, but it is not sheared, and is probably post-Algonkian.

Megascopically, the rock shows prominent and abundant phenocrysts of plagioclase, small ones of hornblende and biotite, and a few rather large rounded ones of quartz, in a fine-grained dark-gray groundmass. With the aid of the microscope it is found that the plagioclase is mostly andesine and that the groundmass consists of plagioclase, hornblende, biotite, much quartz, and a large proportion of orthoclase, which forms irregular poikilitic individuals. On the whole the plagioclase is markedly more abundant than the ortho-

clase, and the rock probably does not differ much in composition from the granodiorite already described.

Area at west base of Cabinet Range.—On the Northern Pacific Railway between Sandpoint and Hope, near the west base of the mountains, there is a small outcrop of granodiorite which is intrusive in sediments corresponding to the Prichard. The igneous rock is evenly granular and is composed of greenish-white feldspar, smoky quartz, and small bright foils of biotite. The feldspar is found microscopically to be mainly plagioclase, and interstitial perthitic orthoclase is seen to occur in rather small amount.

Lightning Creek area.—A mass of granodiorite is seen cutting the old quartizites and argillites on the walls of Lightning Creek canyon a short distance above its junction with the Clark Fork valley. It shows roundish phenocrysts of quartz embedded in a fine-grained base, consisting of dull white feldspar and considerable biotite. Under the microscope the greater part of the feldspar is found to be plagioclase with marked zonal banding.

Area east of Bull Lake.—The mass east of Bull Lake was observed on a fault contact at the border of the valley, and on the ridge above is seen in clearly irruptive relation to the partly calcareous Algonkian strata, in which it has produced striking contact metamorphism. In composition it is similar to the two rocks last described, but richer in biotite. It is chiefly remarkable for a marked schistosity, supposedly induced by powerful drag along the fault that limits the mass on the west.

The existence of a mass of granitoid rock in the basin of Callahan Creek, as rudely indicated on the map, is known only from hearsay and from the presence of float in the lower reaches of the stream. Nothing is definitely known regarding the size and form of its surficial outcrop.

SYENITE.

Occurrence.—Syenite forms a small mass, intrusive in the Prichard formation, on Vermilion Creek near its junction with Clark Fork.

Petrography.—The mass is somewhat variable in composition. Some of it appears megascopically to be almost wholly of feldspar, while other parts contain a considerable amount of a dark prismatic mineral. A specimen illustrating the more feldspathic phase is found on microscopic examination to have perthitic orthoclase for its principal constituent, but to contain also a few small individuals of sodic plagioclase, a very little interstitial quartz, and some deep-green ægirine-augite. Titanite is an abundant accessory. Another specimen representing the more femic phase contains a fairly large proportion of deeply altered plagioclase, which is still, however, sub-

ordinate to the orthoclase. It contains more quartz than the first specimen, and prismatic masses of hornblende and biotite which are thought to be pseudomorphic after pyroxene.

This rock, so distinctly different from that of the intrusive masses to the west, shows marked affinity with the masses of monzonite and syenite exposed to the southwest in the Cœur d'Alene district, which are described in the report on that district.[a] The distinct linear arrangement of all these masses of alkaline rocks, which are the only ones known in this region, is noteworthy and doubtless significant.

BASIC INTRUSIVES.

LAMPROPHYRE.

Occurrence.—In the vicinity of Lake Pend Oreille were seen many dikes of fine-grained, holocrystalline, dark-colored rocks, whose chief constituents are plagioclase, hornblende, and biotite. The last two minerals, especially the biotite, are generally prominent megascopically. These rocks occur in the Cœur d'Alene district, and description of them will be found in the report on that district.[b]

These dikes were seen in greatest abundance on the south shore of the peninsula in Lake Pend Oreille, southwest of Hope. A large number of them, with a north-northwesterly direction and steep dip to the west, there cut the east-dipping rocks of the Prichard formation. Their attitude is about parallel to that of two great faults located farther southwest, and they are probably connected in origin with the faulting. Other dikes of the same character were noted on the railroad west of Hope, and on the east shore of the southern arm of the lake, north of Granite Creek. One at the latter place dips 70° W. and strikes N. 30° W.

Petrography.—The lamprophyres of this region are mostly rather fine grained and very dark, but some of the larger masses have a coarser texture and a lighter hue. The constituents megascopically visible are feldspar, hornblende, and biotite. The dark minerals exhibit notably well-developed crystal form, the biotite occurring in hexagonal tablets and the hornblende in elongated prisms. The feldspar is not conspicuous in the darker and finer grained specimens. By the aid of the microscope it is seen that the feldspar is mainly plagioclase of moderate basicity, the biotite of a deep-brown variety, and the hornblende variable in color, passing from green to brown in the same individual. Some interstitial orthoclase and quartz, usually intergrown, occur in all specimens, and some contain augite.

[a] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Cœur d'Alene district: Prof. Paper U. S. Geol. Survey No. 62, 1908, pp. 45–48.

[b] Idem, pp. 53–54.

DIORITE.

Occurrence.—The name diorite is applied provisionally to a dark, medium to fine-grained rock, rich in hornblende, which in this region forms very numerous tabular intrusive masses in the Algonkian, being confined chiefly to its lower portion. Where their relations are clear they are found to be sills, injected between the strata. These intrusive bodies are most numerous in the northwestern part of the region, and are best displayed along the Great Northern Railway between Bonners Ferry and Lenia. Here they are approximately parallel to the steeply inclined east-dipping strata of quartzite and argillite, but may occasionally be seen cutting the planes of stratification at a small angle. In all cases where this was observed they are steeper than the strata. The thickness of these bodies in this locality varies from a few feet up to several hundred feet. Other masses of the diorite, splendidly exposed on the steep sides of glacial amphitheaters, were seen along the divide between Mooyie and Yaak rivers from the boundary to Mount Ewing, about 6 miles south. The gray Prichard quartzite here dips gently to the east, and the intrusive masses, although they occasionally break across the strata, are clearly seen to be essentially sills. Half a dozen were observed in this vicinity, and some are 300 feet or more in thickness. These rocks were seen at other localities where their relations are not so clearly displayed. They are abundant in the Prichard formation on Yaak River near Sylvanite, on Vermilion Creek, and in the area south of Sandpoint and west of Pend Oreille Lake. Large intrusions of the same character form some of the peaks of the Cabinet Range northeast of Hope. At these places it was not determined whether they were dikes or sills. Similar intrusive masses were observed again, chiefly by Mr. MacDonald, in the Prichard rocks east of Plains. There they were thought by him to be dikes, but they show a trend approximately parallel to the general strike of the rocks—about east and west—and may prove to be sills. Some of the masses here are as much as 600 feet in thickness.

Petrography.—These intrusive bodies consist for the most part of a very dark, somewhat greenish, hypidiomorphic-granular, medium-coarse to fine-grained rock. The most conspicuous mineral, megascopically, is greenish-black hornblende, usually somewhat fibrous, but feldspar and quartz are easily recognizable in all but the finest-grained specimens.

Examined in thin section, this rock is found to be composed chiefly of hornblende, plagioclase, and quartz, with variable but generally small amounts of orthoclase and biotite. The common accessories are iron ore and apatite. The plagioclase crystals generally show far larger extinction angles at the center than on the periphery, but

the more basic grades into the more acidic feldspar, so that distinct zones are not recognizable. The species represented range from labradorite to oligoclase. The orthoclase commonly is intergrown with quartz, which in some specimens is very abundant. The hornblende is the most interesting of the minerals because of its problematic origin. In thin section it usually shows a rather pale green color, irregular boundaries, and splintery terminations. In some specimens it is deeper green and more massive. Although its form is commonly prismoidal, it is, as a whole, of later crystallization than the plagioclase; yet in only one of the slides examined does it show an ophitic relation to the feldspar. While the usual character of the amphibole is similar to that of uralitic hornblende, in none of the many specimens examined was any augite detected. It may be pertinent to note that diabase dikes trending about north-northwest are found in the Cœur d'Alene district, and that the rock forming these is composed essentially of plagioclase, a little quartz and feldspar, and augite that is commonly much uralitized. The rock now under consideration is, on the whole, richer in quartz than the diabase of the Cœur d'Alene district, but otherwise similar except in the absence of augite; and this may be accounted for by the probably lesser age of the latter rock, which cuts across beds as late as Striped Peak, while the diorite sills here described were not seen in contact with rocks younger than the St. Regis. These considerations, together with the character of the hornblende, suggest that dioritic rocks of this region are uralitized diabases and gabbros, and although complete proof is wanting, I am inclined to believe that such is the case.

The feldspar shows abundant evidence of alteration, which has probably taken place under deep-seated conditions. It usually contains numerous well-individualized inclusions, chiefly of hornblende, epidote, and zoisite. The iron ore is commonly replaced by a cloudy "leucoxene," which appears to be chiefly titanite.

A remarkable phenomenon connected with these intrusions has been described in detail and discussed by Daly.[a] He has observed that near the upper surfaces of the great sills the rock changes gradually from hornblende gabbro to granite, and he ascribes this change to assimilation of part of the overlying siliceous sandstone by the magma. Similar observations were made in the region described in this report. I formulated no explanation of them in the field, but read Daly's paper after the season closed, and believe the conclusions therein stated to be essentially correct.

[a] Daly, R A., The secondary origin of certain granites: Am. Jour. Sci., 4th ser., vol. 20, 1905, p. 185.

The two most striking cases of this marginal variation that were observed have been selected for brief description here.

The first occurs a little west of the mouth of Mooyie River, in a great sill about 800 feet thick, which dips steeply east with the inclosing strata. Most of the mass is composed of medium-grained, dark-gray, hornblendic rock, which becomes darker and finer grained near its western or lower side. For a few yards from its eastern or upper side, however, it is variable, but lighter colored on the whole and in part coarser grained. A typical specimen appears, megascopically, as an aggregate of lath-shaped feldspars, abundant quartz, and a moderate amount of hornblende, which forms conspicuous, long, splintery-looking individuals. The feldspar, on microscopic examination, proves to be somewhat more than half andesine, and the remainder orthoclase, which forms laths like the plagioclase instead of occurring interstitially as in the normal diorite.

The second locality is near the junction of Flathead and Missoula rivers. Here along one margin of a large intrusive body the typical diorite passes into a fine-grained pepper-and-salt aggregate of quartz, feldspar, and biotite. With the aid of the microscope it is seen that the feldspar comprises sodic plagioclase and an approximately equal amount of orthoclase. There is a very large proportion of quartz and micropegmatite, and abundant minute particles of biotite are included in the feldspar and quartz. The texture is unlike that of an ordinary granite in that the grains are extremely irregular in form and uneven in size.

A similar rock is extensively exposed at Plains, but here its relations to the diorite were not observed.

VOLCANIC ROCKS.

ALGONKIAN VOLCANICS.

Occurrence.—The only surface volcanic rocks noted in the Algonkian were seen near the forty-ninth parallel, on the high ground between Yaak and Kootenai rivers. They are best exposed in the steep glacial cliffs on the east side of the divide, which exhibit in section about 500 feet of lava, amygdaloid, and tuff, quite clearly extrusive.

Petrography.—These rocks are of a dark-green color, and are greatly altered, but examination of the more crystalline phases of the lava gives some clue to their original composition.

They have a striking porphyritic texture, showing to the unaided eye a dark-green aphanitic groundmass in which are embedded many conspicuous, markedly tabular phenocrysts of plagioclase, with a somewhat parallel arrangement, which attain a maximum length of about one-half inch. The feldspar is colored pale green, evidently

by secondary material. In thin section it is seen that plagioclase is the only original mineral present, and that it forms a second generation of microscopic crystals. The material in which it is embedded is nearly all chlorite. Though clouded considerably with chlorite and kaolin, the feldspar may be determined from its extinction angles to be chiefly andesine. The considerable proportion of iron and magnesia shown to be present by the abundant chlorite, together with the character of the feldspar, indicate that the rock belongs to the andesites or basalts. Comparatively fresh lavas of the same highly characteristic texture as these have been found in the Miocene of Washington,[a] and they contain abundant augite as the only ferromagnesian mineral; it is probable that they should be classified as augite andesites.

MIOCENE BASALT.

Occurrence.—Just northeast of Spokane the west base of the rounded hills of old crystalline rocks north of the river valley is seen to be skirted by a horizontal terrace of basalt, which connects with the great volcanic sheet that underlies the Columbia Plain of eastern Washington. This terrace is continued eastward by a line of isolated, level-topped masses of basalt on either side of Spokane Valley. Similar basalt terraces are seen all about the shores of Cœur d'Alene Lake, along the western base of the Cœur d'Alene Mountains for some 14 miles north of the lake, along St. Maries River beyond the mouth of the St. Joe, and for several miles up Cœur d'Alene River.

It is about Cœur d'Alene Lake, and especially in the vicinity of Harrison, by the mouth of Cœur d'Alene River, that these terraces are most extensive and conspicuous. Their height above the water level at Harrison is about 500 feet, but it is 200 to 300 feet more at the north end of the lake. This may be due to the initial slope of the lava away from its source to the west, but this supposition can not be established without more observation.

Character.—The basalt is a dark, heavy, black rock, more or less crystalline and rather fine grained. It shows the characteristic columnar parting in places, and the upper parts of the layers have the vesicular character of surface flows. Detailed petrographic descriptions of this lava have appeared in several publications[b] and need not be repeated here. It belongs in general to normal basalts, with or without olivine. The one specimen taken on Lake Cœur d'Alene contains none of that mineral.

---

[a] Snoqualmie folio (No. 139): Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 9.

[b] See, for example, Smith, G. O., Mount Stuart folio (No. 106), Geol. Atlas U. S. U. S. Geol. Survey, 1904; Smith, G. O., and Calkins, F. C., Snoqualmie folio (No. 139), Geol. Atlas U. S., U. S. Geol. Survey, 1906; and Calkins, F. C., Bull. Dept. Geology Univ. California, vol. 3, 1902, pp. 159–166.

STRUCTURE.

GENERAL STATEMENT.

The region is characterized structurally more by faulting than by folding. Very few folds in the region can be traced for great distances, but a number of faults, some of which are of enormous throw, have been followed for many miles. The blocks between the faults are generally much tilted, and steep dips persist in places for long distances across the strike. The Cœur d'Alene district is an area of exceptionally complex deformation, this fact being probably in large measure the cause of its richness in fissure-vein deposits.

The map shows the principal faults detected in the reconnaissance and also a few of the more extensive ones in the Cœur d'Alene district. Only the greatest faults can be represented with approximate correctness on a map of such diminutive scale. For some of those indicated for only short distances the direction has not been accurately determined. The most important faults have been given names, indicated on the map, by which they will be referred to in the text. The strike and direction of dip of the strata, where they are persistent over wide areas, have also been shown on the map.

FAULTS.

GENERAL CHARACTER AND EXPRESSION IN TOPOGRAPHY.

The great faults of the region are mostly steep, and probably the majority of them are normal, although a normal character has not been actually proved in many cases. The downthrow of all the steeply inclined faults, except the great Lenia fault and the one west of Bull River, is to the west and south. The strike of all except the Hope fault is approximately that of the dislocated strata, and the downthrow to the west is generally opposed to an easterly dip; or, in other words, the prevailing kind of dislocation is step faulting. The fault just east of Bull Lake is the only overthrust clearly shown to be such that was found outside the Cœur d'Alene district.

The marked extent to which the great faults are expressed in the topography can not be appreciated fully without the aid of a contour map, yet it is illustrated by the approximate coincidence of certain stretches of Clark Fork and Kootenai River with fault lines, which the small reconnaissance map shows. The crushing that has taken place along planes of movement has tended to the formation of valleys along fault lines. The course of the Hope fault is marked by a line of depression that separates a range of hills from the main Cabinet Range; the depth of the broad pass in which Bull Lake is situated is probably due in part to easy erosion along a zone of faulting; and

other instances of this kind of topographic expression will be cited when the faults are described in detail.

Of true fault scarps the region affords no proved examples. Several features, taken by themselves, might be thought to exemplify this phenomenon, and the most apt for such an explanation is perhaps the Hope fault. On the north side of this dislocation the Cabinet Range rises abruptly, with a steep and fairly regular frontal slope and the topographic character of a dissected plateau, while on the south or downthrown side lies a range of rather flat-topped hills. These facts accord with the supposition that the tops of both the mountains and the hills are remnants of a single peneplain which has been dislocated by faulting. If this be true there can be no doubt—since the hills are carved in younger rocks than the mountains—that the peneplain was developed only after a displacement of several thousand feet had occurred, and that subsequently to the development of the peneplain a smaller displacement, equal in amount to the difference of elevation between the two dissected plateaus, has taken place on the same fissure.

But the hypothesis of direct physiographic expression of faulting, as applied to this case, can hardly be considered proved, for there is an alternative which appears to me at least equally competent to explain the facts. The greater topographic elevation of the upheaved block along the Hope fault is naturally accounted for by the superior resistance of the quartzitic rocks north of the fault as compared with the calcareous shales to the south, and the flat tops of the hills in the valley may represent an old valley level.

All the other apparent instances of direct topographic expression of faults in this region that can be recalled at present may similarly be explained as the result of differential erosion. Moreover, in some places the topographic evidence is opposed to the supposition of direct expression of tectonic movements. The most striking evidence of this kind is afforded by the part of the Snowshoe fault that is near the Snowshoe mine. There the downthrown block, on the west, is topographically the more elevated.

DESCRIPTION OF PRINCIPAL FAULTS.

Lenia fault.—The Lenia fault, named for a railway station near which it passes, has a course of about north-northwest and has been traced, though not continuously followed, from the mouth of Mooyie River to a point near the junction of Keeler and Lake creeks. It has a steep dip, whose direction is not certainly known, and the downthrow is on the east. Excellent opportunity to observe the character of the fault zone is afforded by the numerous cuts along the Great Northern Railway in the vicinity of Lenia. About a mile and a half

northwest from the station the track crosses the fault, which can there be located within a few feet. There is intense disturbance and crushing for some yards on either side the fissure, which seems to be nearly vertical, but within a short distance may be seen the gray Prichard quartzite on the southwest side and green shales, with purple beds and thin layers of limestone, supposedly belonging to the Newland, on the northeast side, both dipping toward the fault at angles of 50° to 60°. The throw here, being equal to about twice the thickness of the strata intervening between the horizons brought together by the fault, must be more than 15,000 feet.

The fault crosses Callahan Creek at a point not accurately located, but a few miles from its mouth. Here it seems to bring Striped Peak against Prichard. The promising "Big Eight" and "B. & B." mines on this stream, in slates and quartzitic sandstones of the Prichard formation west of the fault, are located on fissures whose course is about parallel to this great dislocation and which dip steeply to the west. The suggestion arises that the Lenia fault may be of the steep reversed type, of which many examples are found in the Cœur d'Alene district.

The fault is expressed strongly by the topography, for it has partly determined the course of Kootenai River, which flows directly along the fissure for a short distance northwest from Lenia. It also has determined the location of several saddles between the river and Lake Creek.

Snowshoe fault.—The Snowshoe fault is conspicuous in the vicinity of the Snowshoe mine, about 20 miles south of Libby, whose ore body is in the main fault fissure. In the workings of the Snowshoe mine the fissure strikes nearly north and south and is almost vertical, but dips on the whole a little to the west. This is also the side of downthrow, for the country rock east of the fault is purplish-gray quartzite, which is referred to the Burke formation, while to the west it is calcareous shaly material, very similar to the typical Newland, but referred to a horizon even higher. The throw here must be considerably more than 6,000 feet, probably fully 10,000 feet. Contrary to what might be expected in view of this great displacement, the fissure as seen underground is remarkably clean cut; the Snowshoe vein is for the most part only about 5 feet wide, and the rocks that constitute its firm, well-defined walls exhibit little disturbance. The small amount of crushing that has taken place in the fault zone accounts for the comparatively slight expression of the fault in the topography. In the vicinity of the Snowshoe mine the spurs are rather sharply notched where it crosses, but its course to the south, across a lofty portion of the Cabinet Range, is not marked by any conspicuous depression. The sharply defined character of the Snowshoe fault is

probably due to its nearly vertical attitude, which allowed the movement to take place with a minimum of friction.

For some distance south of the Snowshoe mine the fault was not directly observed, but its southward continuation is thought to be indicated by a fault contact clearly exposed on the north side of Clark Fork valley about halfway between Thompson and the mouth of Vermilion Creek. There the high bluffs that overlook a bend of the river show disturbed red and green shales, probably belonging to the St. Regis and Newland formations, dipping to the east toward westward-dipping Prichard argillites. The fault has here had some influence on the location of the east wall of the valley, and it disappears to the south under the alluvium.

Hope fault.—The Hope fault has been traced approximately from Hope to Heron in the valley of Clark Fork. The course of the fissure is marked by a trench dividing the Cabinet Mountains proper from a zone of much lower hills that lie between the range front and the river. The fact of faulting is clearly established by the relations of the rocks of the hills to those of the mountains. The rocks of the Cabinet Mountains in this vicinity belong to the Prichard, Burke, and Revett formations, whose strike makes a large angle with the course of the dividing trench and whose dip is east, while the valley hills are composed chiefly of Newland rocks, with some St. Regis and Striped Peak beds, which also dip east from Hope to Clark Fork. The hill tract has therefore been carved from a block which has been greatly depressed with reference to that which forms the mountain tract. South of Scotchman Peak, for example, the base of the Burke is brought against Striped Peak rocks, involving a displacement of not less than 12,000 feet. The dip of the fissure is not known, but it is probable that, like the majority of fissures observed in this region, it dips to the southwest, and that the fault is normal.

Bull Lake fault.—The fault east of Bull Lake differs markedly in character from those described in the preceding paragraphs. It is an overthrust, dipping 45° W. The force which produced it produced also a strong and extensive schistosity in the granite east of it, and intensely sheared and crumpled the sedimentary rocks in its vicinity farther south. Its throw, although probably amounting to some thousands of feet, is not known with any definiteness, while its extent north and south from the points where it was actually located is uncertain. It is thought that it probably extends at least as far north as Station Creek and as far south as the lower forks of Bull River. The evidences that indicate the character of the fault will be described in detail later. (See p. 66.)

Evidences of faulting along Purcell trench.—Mr. Ransome, who reconnoitered the western part of this region in 1901, suggested in conversation the idea that the Purcell trench might have been determined by a great fault, with the downthrow to the east, which dropped the Algonkian down against the Archean. The existence of such a persistent and straight valley is in itself suggestive of faulting. My endeavor to verify this hypothesis did not lead to definite proof of extensive dislocation. The boundary between the Algonkian and the Archean is covered at the south by basalt and alluvium, and farther north is invaded by post-Algonkian granitic intrusions. Some evidence of faulting along this trench was found, however, and may be briefly stated.

In the railroad cuts just north of Porthill there are exposed gray quartzites and shales belonging to the lowest formation of the Algonkian, and these are cut by a basic dike. The sediments are much fissured and mineralized, and the basic dike, which is greatly altered, has a distinct vertical schistosity that strikes about north and south.

These phenomena are indicative of faulting about parallel to the valley.

The gneissic banding also that is developed in the granite or quartz monzonite at Bonners Ferry and to the south may be due to shearing in a zone of faulting.

Again, although along the western base of the Purcell and Cabinet mountains the strata dip eastward and belong to the lowermost division of the series, farther south the structural trend makes a considerable angle with the line of the Purcell trench, and areas of strata so high in the series as the Newland formation extend to the western limit of the Algonkian belt. The lack of concordance in this vicinity between the course of the dominant topographic feature and that of the structural axes and faults to the east of it might have been produced by faulting.

FOLDS.

In the northern part of the region the strike of the rocks is notably uniform and is, on the average, a little west of north. In the southern part, and especially in the Cœur d'Alene district, it is far more variable, but is most commonly near west-northwest. As has already been mentioned, few extensive unbroken folds can be traced. The greatest one recognized is an anticline that runs along the northeastern side of the Cabinet Range. Its course is about north-northwest, and it makes an oblique angle with the Snowshoe fault, which cuts off a part of its western limb, so that in the vicinity of the Snowshoe mine only its eastern limb is seen. At the head of Fisher River, however, a fine section across the crest of the arch is

exposed. Here in the axial portion typical Prichard slate appears, and this is flanked on either side by quartzite of the Burke formation.

A clearly synclinal structure is exhibited along the international boundary between Yaak River and the crest of the Kootenai-Yaak divide, but this syncline was not traced far along its axis.

The gorge of the Kootenai between Troy and Libby exposes several folds in section. There are a number of small folds just below the falls, and a broad syncline and anticline above.

The canyon of Clark Fork between Thompson and Plains cuts across an anticline in quartzitic rocks of the Ravalli group and a broad syncline that shows shale and limestone of the Newland formation in the axis, underlain by these quartzitic rocks on either side.

CHAPTER III.

AREAL GEOLOGY.

GENERAL STATEMENT.

The purpose of this chapter is twofold. It will present many details regarding local stratigraphy and structure which could not well be included in the general discussion that formed the last chapter, and it will enable those who for economic or scientific ends desire information concerning the geology of any particular portion of this region to find facts relating to that portion which may serve their purposes or guide them in more detailed studies.

To arrange the subject-matter of this part of the report is somewhat difficult because the examination of the region was necessarily incomplete and uneven. To discuss the geologic features of the principal mountain groups in turn would hardly be practicable, inasmuch as there are large areas in each range regarding which no details are known. It has therefore seemed best to subdivide the account of the areal geology under headings that designate sections into which the route of the party may conveniently be divided. These sections, together with the areas explored in their vicinity, will be described in the order in which they were traversed.

DETAILED DESCRIPTIONS.

CŒUR D'ALENE AND SPOKANE VALLEYS.

The Algonkian rocks along Cœur d'Alene Valley and the wagon road from the mining district to the lake belong to the Prichard and Burke formations, the former predominating. The prevailing strike is about east and west, and the prevailing dip a moderate one to the north. What is taken to be the continuation of the Osburn fault, of the Cœur d'Alene district, crosses a saddle behind a knob across the bridge from Cataldo. It brings northward-dipping Burke beds down against the shale of the Prichard formations. Two other saddles, east and west of Kingston, which were once occupied by the river, are in line with this one and with the course of the Osburn fault as traced in the Cœur d'Alene district, and they are believed to have been determined by relatively rapid erosion along the fault fissure.

The most important stratigraphic observation made in this valley was of the gradual change in the character of the Prichard forma-

tion along its strike. The change is not so marked, however, as to lead to danger of confusing the Prichard with any other formation of the region. The dark-blue fine-grained banded slate or argillite that is the dominant phase of the Prichard in the Cœur d'Alene district simply becomes on the whole more siliceous, coarser grained, and of a grayer tint, with a tinge of green in places.

The first gneiss met with along the route forms a small hill on the lake shore near Cœur d'Alene. It is separated from the nearest outcrop of Prichard by a terrace of basalt. Gneiss is exposed on both sides of the narrows where the main north-south body of the lake begins. On the east it is overlain by basalt, which presumably covers the contact between the gneiss and the Algonkian rocks. The south shore of the east arm was not examined, however, and might furnish some clue as to the relations of the two systems.

The valley of Spokane River affords other good exposures of the gneisses, already mentioned on page 33. One of the most interesting features of the geology of this section is the occurrence of basalt terraces which are remnants of tongues that projected up the pre-Miocene valley from the great basalt floods of the Columbia Plain. These are to be seen at intervals along Spokane Valley, are developed to a large extent about the shores of Cœur d'Alene Lake, and are found in the lower part of the valleys of Cœur d'Alene and St. Joseph rivers.

BETWEEN CŒUR D'ALENE AND PEND OREILLE LAKES.

The hills extending from Cœur d'Alene north-northeastward to Lake Pend Oreille are composed of Algonkian rocks. South of Canfield Butte—a hill south of Hayden Lake—these rocks resemble the Prichard formation, but that elevation seems to owe its prominence to silicification along a fault which brings the Prichard on the south against a formation on the north which resembles the Newland. This formation was also observed on Hayden Creek, where it has the aspect of typical middle Newland, also about 2 miles northwest of the head of Hayden Lake, where it is evidently metamorphosed by the neighboring monzonite and does not weather in the same yellow tints that characterize the typical Newland. The rocks of Chilco Mountain are mostly thin-bedded quartzites, of greenish hue, which in places grade into hard white quartzite or purplish siliceous argillite. They dip under Newland rocks and are supposed to correspond to the St. Regis formation. Bernard Peak is composed of white, green, and purplish-brown, fine-grained, thin-bedded rocks which weather as though calcareous and prove on microscopic examination to be composed essentially of quartz, carbonate, mica, diopside, and a pale-green amphibole. Evidently these rocks are such as might be derived

from siliceous and magnesian limestones by contact metamorphism, and they strongly resemble metamorphosed phases of the Newland ("Wallace") formation in the Cœur d'Alene district. They dip southward toward the basin of the Little North Fork of Cœur d'Alene River, where the Newland formation, with its typical aspect, is well developed.

A trip into the drainage basin of the Little North Fork resulted, owing to the heavy cover of brush and forest, in little except the general observation that the rocks of this vicinity are chiefly sediments belonging to the pre-Cambrian formations that prevail in the Cœur d'Alene district. There is a vast development of Newland in the northern part of the basin, while farther south there occur white quartzites, partly pure and partly sericitic, which correspond to the Burke and Revett formations in the Cœur d'Alene district. Certain observations made during this excursion, as well as facts related in conversation by Mr. Leiberg, were interpreted as indicating that several faults crossed the river, probably with a direction approximately east and west. South of Lakeview for many miles, in both the Clark Fork and the Cœur d'Alene drainages, the prevailing rocks are typical Newland. They were found overlain and underlain by purplish quartzitic beds assigned to the Striped Peak and St. Regis formations, respectively. These two formations are apparently brought together by a fault, which was not exactly located, a few miles southeast of the head of Lake Creek.

LAKE PEND OREILLE.

The steep rocky shores of Lake Pend Oreille afford excellent exposures and were examined throughout their extent with the aid of a launch. Considerable information was thus gathered concerning the stratigraphy and structure of the vicinity. Most of the rocks were of sufficiently familiar appearance to be correlated confidently with the formations of the Cœur d'Alene district, but the place in the stratigraphic series of the pure limestones exposed about the south end of the lake (p. 42) is still problematical. In the following brief description of the shores, the southern portion, upon which the limestones are exposed, will be left until the last.

The western shore from Cape Horn northward is made up of rocks of the Newland formation, the underlying quartzitic Ravalli group, and the Prichard formation. These have prevailingly an eastward dip and are broken by step faults with downthrow to the southwest. Cape Horn is composed of a granodiorite which a few rods northward is seen in irruptive contact with metamorphosed purplish-gray shaly sandstones that correspond to the St. Regis formation. Along the crescentic curve of the shore to Blacktail Point the rocks have the typical aspect of the St. Regis and Newland formations. They gen-

erally dip toward the lake, but there is much variation in their attitude. The contacts between the two formations are not generally well exposed, but it seems probable that most of these contacts are faults. The gulch just southwest of Blacktail Mountain certainly marks the position of a great fault, with downthrow on the southwest. South of the gulch the country rock is the most typical middle Newland, dipping in general eastward, but showing much contortion and fracture and cut by several small veins. North of it is a high, steep-sided promontory carved from purplish-red and green sandy shales like typical St. Regis, also dipping eastward. Farther along the shore these beds are again conformably succeeded by calcareous shales of the Newland formation. These form the country rock of the mine east of Blacktail Mountain, along the eastern base of which runs another fault, similar in strike and direction of movement with the one mentioned just before, but exceeding it in amount of throw.

Just northeast of the little embayment at Blacktail purplish quartzite, probably corresponding to the Burke formation, much disturbed, veined, and broken, has been brought against the Newland by the Blacktail fault, and is apparently faulted again farther on against bluish thin-bedded shales, with interbedded gray impure quartzite, which are taken to correspond to the Prichard formation. These latter rocks are almost continuously exposed to the northern end of the lake. Along the shore the general dip is eastward, with some variation. It is probable, however, that this dip is offset by other lesser faults in addition to those already mentioned. One of these probably determines the location of Garfield Bay. In its vicinity the sedimentary rocks are cut by numerous basic dikes, which commonly accompany known faults in other parts of the region, and on the west side is a mine on a rather ill-defined zone of brecciation.

The north shore was examined by following the Northern Pacific Railway from the west base of the mountains to Hope, the almost continuous cuts revealing a succession of the same bluish and gray argillites and quartzites that are seen along the northwestern shore of the lake. There is much of this material that resembles the Prichard formation, but hardly any so argillaceous as the dominant phase of rock in the type localities. The most abundant species is an indurated, fine-grained, sandy shale or shaly sandstone. The sedimentary rocks are cut by a large number of dikes, both acidic and basic, and at the west base of the mountains by a batholithic mass of granodiorite. Eastward the good exposures are interrupted for a short distance, but on Mameloose Island, southeast of Hope, they are continued by outcrops of greenish-gray siliceous shales, again dipping eastward, which resemble and are probably to be correlated with the Burke. The outcrops, followed along the lake, show occasional transition to purplish beds and whitish quartzitic beds. These in

turn are overlain near the east end of the lake by purple, maroon, and green beds of rather bright tint.

Along the south side of the eastern arm of the lake the high bluffs give excellent exposures of the Newland, underlain by purple beds like typical St. Regis, these in turn by more grayish quartzites resembling the Burke, though rather purer and thicker bedded. (See Pl. II, *B*.) There is here no distinct heavy stratum of white quartzite corresponding to the Revett quartzite of the Cœur d'Alene district. These rocks are underlain by bluish shales similar in character to those of the Prichard formation, but thinner bedded and without slaty cleavage.

Along the eastern shore of the lake to Lakewood the exposures are more diversified, and sedimentary rocks alternate with intrusive masses of granitic rocks whose occurrence is the chief feature of interest on this shore.

The limestone referred to on page 42 is exposed west of Cape Horn along the north side of Squaw Bay. It has here been rendered coarsely crystalline by the granodiorite intrusion, and in the quarry of the Washington Brick and Lime Manufacturing Company shows no recognized bedding. No clue to its stratigraphic relations can be gained at this locality, for it is not seen in contact with any other sedimentary rocks. On the southern shore, however, there is more hope of solving the problem.

The section along the shore west of Lakeview exhibits an eastward-dipping succession, in descending order, of limestone, quartzite, and bluish shale, the last-named rock probably being separated by a fault from the Newland beds that form Bernard Peak. The contact between the limestone and the quartzite is faulted, but the impression was gained that the fault is not of large throw. East of Lakeview also this main mass of limestone is cut off by a fault. A little farther northeast, however, the limestone is again seen apparently overlying bluish shale and quartzite. In the valley just southeast of Lakeview the limestone is seen faulted against quartzite on the east, but the character of its southern boundary was not made out. A little farther south the blue shale like the Prichard was seen in fault contact with typical Newland.

From these observations it appears probable that the limestone immediately overlies quartzites and shales. These latter rocks bear some resemblance to Prichard and Burke respectively, but it is a significant fact that the quartzite has in part a very coarse-grained, pebbly character, unlike that of any rocks undoubtedly belonging to the Burke or other members of the Ravalli group. The lithologic resemblance is not necessarily significant, therefore, and these shaly and quartzitic rocks may belong to a horizon above the Striped Peak. This appears the more probable because of the difficulty in account-

A

B

VIEWS ON LAKE PEND OREILLE.

ing for the development of several hundred feet of limestone at a horizon that shows no trace of calcareous material anywhere else in the district.

CLARK FORK VALLEY BELOW VERMILION CREEK.

The dominant structural feature of the valley from the lake to Heron is the Hope fault, which profoundly affects the areal distribution of the rocks. The hilly space between this fault and the river is occupied by rocks of the St. Regis, Newland, and Striped Peak formations. From Hope to Clarkfork the rocks exposed along the railway and the wagon road have an eastward dip that gradually diminishes from about 60° to almost 0°. They are chiefly Newland, but at Thornton siding, a few miles east of Hope, several hundred feet of beds like typical St. Regis, underlain by more massive purplish quartzite, are brought up by a fault with upthrow on the east, whose displacement must be at least 4,000 feet. East of Clarkfork the Newland is overlain by shaly siliceous beds, chiefly maroon in color, but with some green layers, which correspond in general character and stratigraphic position with the Striped Peak formation of the Cœur d'Alene district. Between Clarkfork and Heron the structure is in general synclinal, and to the east the Newland becomes the prevailing rock. There are some small folds and apparently some faults, both parallel to and across the strike, but these minor structural features were not worked out.

South of the river in this portion of the valley less thorough examination of the ground was made. The rocks there also are chiefly Newland and Striped Peak, the red beds of the latter being extensively developed south of Heron, where they have a thickness, according to Mr. MacDonald's observations, of more than 2,000 feet, their upper limit not having been observed.

The mountains north of the great fault were ascended northeast of Hope, in the neighborhood of Lightning Creek and north of Heron. They were found to be composed of rocks stratigraphically beneath the Newland, with a general moderate dip to the east, although there is local disturbance near Lightning Creek. From their western base to Lightning Creek they are composed of the gray quartzites and gray to bluish argillites that correspond in position to the Creston quartzite as described by Daly, and seen by me along the forty-ninth parallel, but intermediate in lithologic character between that formation in its typical aspect and the Cœur d'Alene phase of the Prichard formation. The prevailing eastward dip is somewhat variable in amount, but averages about 30° for at least 10 miles across the strike, indicating a thickness of about 26,000 feet. There is strong probability, however, that this is greatly in excess of the actual thickness of the beds, whose great width of outcrop across the strike may be due

in large measure to step faulting, of which examples at Thornton and along the west side of Lake Pend Oreille have already been mentioned. North of Hope the dioritic intrusives described on page 48 are well displayed.

The ascent of Scotchman Peak, east of Lightning Creek, afforded some observations throwing light on the stratigraphy of the lower part of the Algonkian. The ascent was made by way of the first large tributary of Lightning Creek entering it on the east above its mouth, which affords an excellent section in which the general dip is about 20° E. Near the mouth of this tributary the country rocks are the impure gray quartzites with thin beds of argillite so extensively exposed farther west. These are overlain by about 2.000 feet of dark-blue banded argillite, exactly similar to the typical Prichard as developed in the Cœur d'Alene district. Overlying this material are the light-colored siliceous beds that form Scotchman Peak. These are thin-bedded, ripple-marked, and sun-cracked sericitic quartzites of a gray color, generally tinged with green and purple, almost identical in appearance with the Burke formation in its type exposures. On the north-south ridge of which Scotchman Peak forms a part, and in the profound canyon of the west fork of Blue Creek east of the ridge, these beds are most impressively displayed to a thickness estimated at about 5,000 feet, and they here exhibit no evidence of faulting.

Eastward for several miles from this locality the only observations of the Cabinet Mountains along the Clark Fork valley consisted in long-range views from the south. These showed that in the untraversed section the eastward dip persists, and that quartzites continue to be the prevailing rocks. Looking about north from Heron, however, on the east side of a deep canyon conjectured to be that of the east fork of Blue Creek, one sees a great thickness of rocks that appear darker than the quartzites, and these may be Prichard slate brought up by a fault. Without some such faulting it would be difficult to account for the very great apparent thickness of the quartzite along this section, as compared with that in the Cœur d'Alene district.

The ascent northeast of Heron gave opportunity to observe a part of the quartzitic Ravalli group, and it was found here to comprise a thick stratum of hard white quartzite similar in character and position to the Revett quartzite of the Cœur d'Alene section. Its base was not seen, but it outcrops extensively along a prominent and rugged ridge, and was estimated to be at least 1,000 feet thick. On the east the quartzite is limited by a fault, shown on the map, which has brought it against typical Newland beds.

The quartzitic group being thus cut off, the Newland formation becomes the principal country rock on both sides of the Clark Fork

valley, continuing eastward on the south side nearly to Thompson and on the north side to the Snowshoe fault. The portion of this stretch extending from Bull River to Vermilion Creek was traversed only by train, because its geologic simplicity seemed to make more detailed examination needless for reconnaissance purposes. The eastward dip of the Newland west of Bull River is rather steep, but opposite the mouth of that stream the bedding is almost horizontal, and thence to Vermilion Creek it exhibits gentle undulations.

BULL LAKE VALLEY.

The trench in whose center Bull Lake is situated and which is drained by Bull River and Lake Creek is so well defined a topographic unit that its geologic features may be described together.

Observations along Bull River.—Along the lower, narrow portion of Bull River canyon the rocks are shaly argillaceous beds ascribed to the Newland formation because of their close lithologic similarity to the beds in the Cœur d'Alene district described as the "Wallace" formation. Along the lower and middle parts of Bull Lake valley these beds exhibit some folding, but their dips are prevailingly easterly and northeasterly. The Newland continues on the east side of the river nearly as far as Bull Lake, but not so far on the west side, for the fault observed northeast of Heron apparently crosses the stream, as shown on the map (Pl. I).

This fault was observed in a gulch west of a point at about the middle of Bull River valley. Here are exposed purple and green shales of the St. Regis formation, overlain by typical lower Newland beds, dipping gently to the east and abutting against brecciated white quartzite. The plane of contact appears to dip steeply west, which would imply reverse faulting, but this could not be proved without more thorough examination.

West and southwest of Bull Lake are extensive outcrops of quartzite, seemingly for the most part to be correlated with the Burke formation; and several hundred feet of greenish, more or less sericitic quartzites with some purplish bands are exposed in a remarkable defile just west of Bull Lake. This is a straight north-south ravine, bounded on both sides at the top by cliffs, from both of which descend talus slopes that merge at the bottom. The cliff on the west rises about 1,600 feet to a plateau surface, and that on the east, several hundred feet lower, joins a smooth brushy slope that descends to the lake. In the west cliff the beds are about horizontal; in the east cliff they dip gently eastward. This feature is supposed to have been formed by a huge landslide that caused the mass east of the

ravine to slide downward toward the lake, toward which it became somewhat tilted. A view of it is shown in figure 2.

Bull Lake fault.—The phenomena that accompany the Bull Lake fault, already mentioned on page 55, must be described in some detail, both because it is partly from them that the character of the fault has been inferred and because they are of remarkable and unusual character.

The fault is best displayed at the side of the valley a little south of east from the north end of Bull Lake, and the relations in this vicinity are diagrammatically indicated in figure 3. On going from the road up a certain small stream that there descends from the mountains, one finds a few outcrops of unmetamorphosed shaly sedi-

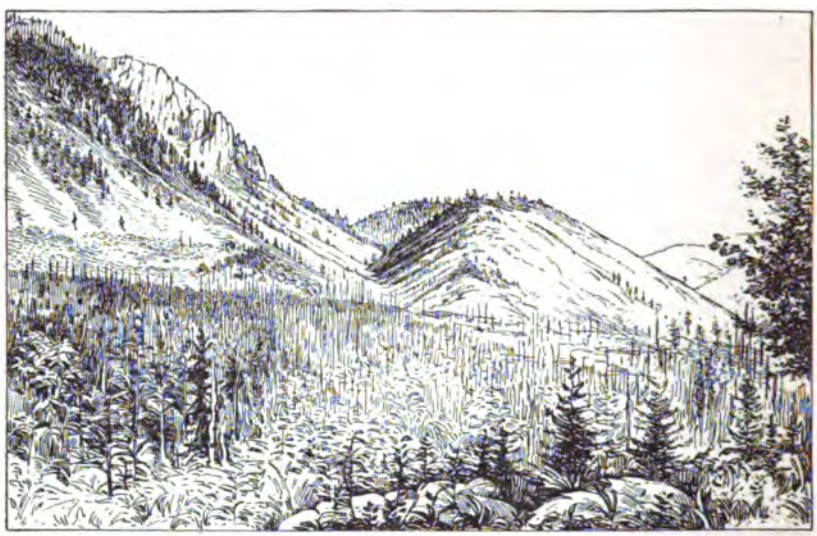


FIGURE 2.—Landslide west of Bull Lake.

mentary rock, dipping gently east, mantled by a heavy deposit of gravel. Proceeding, one comes to a place where, from the gently sloping floor of the broad valley, there rises abruptly a north-south slope, which for a few yards from the base is virtually a plane, with an inclination of 45°, but which becomes gentler and much less even above. The stream cascades down the steep incline, into which it has cut a trench.

The rock which forms this slope is a greenish-gray gneiss whose lamination is parallel to the smooth westward-dipping basal facet. Just south of the fall this regular surface is coated by a siliceous iron-stained breccia that contains extremely sheared and decomposed fragments of the gneiss. A few hundred yards farther north there is seen just west of the gneiss a mass of white siliceous sinter which is evidently a hot-spring deposit.

It is evident from these facts that this smooth rock slope is the foot wall of a fault fissure. Its freshness, relative smoothness, and regularity suggest that it may be a normal fault scarp, on which movement with relative lowering on the west side has taken place in comparatively recent time. It does not seem improbable that recent movement in this direction may have taken place, but it is believed, for reasons presently to be stated, that the main movement on the fissure has been an overthrust with relative upheaval on the west.

Some evidence for this view is given by the gneissic banding of the igneous rock. Since this is parallel to the fault fissure, it is believed to have been produced by the same force. The tremendous pressure necessary to have sheared the rock so thoroughly can hardly be accounted for by friction evolved in normal faulting on a plane of 45° dip,[a] but it might have been produced by the great tangential compressive strain involved in the production of a reversed fault.

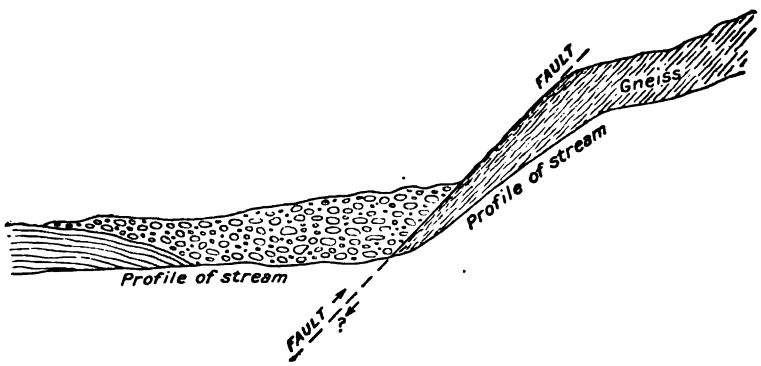


FIGURE 3.—Diagrammatic section across Bull Lake fault.

Additional evidence bearing on this matter, and striking proof of intense dynamic action, are observed in line with this fault at the forks of Bull River southeast of the lake. At the foot of the spur between the forks there are outcrops of sedimentary rock so intricately crumpled and so greatly altered that at first sight they were taken to belong to a pre-Algonkian complex. The minute folds were found to be recumbent toward the east, which should be the case if they were produced by overthrusting from the west. To the east, however, these intensely deformed rocks pass gradually into regularly dipping beds resembling the Newland, which are in turn overlain by a thick accumulation of tough, fine-grained, dark greenish-gray rocks unlike any in the Cœur d'Alene district and believed to be stratigraphically higher than the Striped Peak formation. A mile or so south of the forks there is a low saddle, west of which is a

[a] A gneissic structure induced in a granitic rock by friction on a plane of normal faulting with very low dip is described by Lindgren in Prof. Paper U. S. Geol. Survey No. 27, 1904, pp. 47–48.

hill composed of eastward-dipping Newland, which is practically continuous with the undoubted Newland of Clark Fork valley. It was inferred from these relations that the Newland on the west was thrust by this fault against similar beds on the east younger than the Striped Peak, whose characteristic red shales, though developed typically and in great thickness in Clark Fork valley, do not appear at this locality. Thus stratigraphic as well as structural evidence indicates an overthrust dipping to the west.

Sediments east of Bull Lake fault.—Observations on a great thickness of the sediments east of the Bull Lake fault constituted the chief result of a traverse from the upper forks of Bull River to the highest of the conspicuous isolated group of jagged peaks about 5 miles east. These mountains are carved from a remarkably homogeneous mass of tough, fine-grained, rather siliceous rocks of greenish-gray color. They weather in thick ledges, but show rather narrow bands parallel to the planes of stratification. They resemble some of the material in the Burke formation, but the Burke beds which are exposed in the near neighborhood are as a whole much lighter in color and are more siliceous. The thickness of these beds here exposed is about 5,000 feet, and they are underlain near the forks by partly calcareous beds resembling the Newland. At the western limit of their exposure they are vertical and strike northwest, but farther east they flatten out and show several small open folds. The steep sides of the peaks exhibit fissures along which small displacements appear to have taken place.

Farther northward a spur of the range just north of Station Creek was ascended. The rocks seen near the base of the spur are bluish and greenish shales dipping eastward, succeeded by red shales. These give way—so abruptly as to suggest faulting, possibly the continuation of the Bull Lake fault—to greenish quartzites underlain by siliceous argillites, mostly greenish gray, occasionally purplish, with some thin beds of white, yellow-weathering limestone. This aggregation of rocks differs materially from any of the formations seen in the Cœur d'Alene district, among which the Newland ("Wallace") most resembles it. These rocks differ widely, however, from the Newland exposed in Clark Fork valley within a distance far smaller than other intervals through which the formation retains its essential characters. It is therefore thought that these beds belong to a horizon above any represented in the Cœur d'Alene district.

KOOTENAI VALLEY FROM TROY TO BONNERS FERRY.

The dominant structural feature of the Kootenai Valley between Troy and Bonners Ferry is the Lenia fault, which plays a rôle similar in character and importance to that of the Hope fault in Clark Fork valley. Like the Hope fault, it brings Newland and Striped Peak

beds down against the older rocks that form most of the western part of the Cabinet Range. The course and character of this fault have already been described on page 69, and we may confine most of our attention here to observations bearing on the stratigraphy of the Prichard formation as seen west of the fault and of the Striped Peak, Newland, and older rocks exposed east of the fault.

The railroad section from Bonners Ferry to Lenia affords excellent exposures of thousands of feet of impure quartzites and argillites. Their strike and dip are very constant, and do not vary much from N. 15° W. and 55° E., respectively. They show no evidences of extensive faulting, although they are cut by small slips which increase in frequency as the great Lenia fault is approached. Lithologically the rocks have a strong general resemblance to those exposed along the Northern Pacific Railway west of Hope. In the western part of the section hard, moderately thick-bedded, gray quartzites prevail. To the east bluish argillaceous beds become increasingly abundant, but without forming any thick strata free from quartzitic material.

The rocks exposed west of the fault on Callahan Creek, to the south, are believed to be stratigraphically higher than those described in the preceding paragraph, not only because the strike of the beds diverges in this direction from the course of the fissure, but also because of their lithologic character. In the vicinity of the B. & B. mine is exposed blue banded argillite showing the strongly characteristic features of the prevailing rock of the Prichard formation as developed in the Cœur d'Alene district. The thickness of this material is not determined, but amounts at least to several hundred feet. It dips southeast, apparently under the gray quartzitic rock of the Big Eight mine, which may belong to the base of the Burke. Typical Prichard slate is also exposed southward along the fault as far as the mouth of Keeler Creek, and forms the country rock of other mines in the vicinity of Grouse Mountain.

East of the fault and north of Callahan Creek is exposed a good section of the Newland formation overlain by a little Striped Peak. At the western edge of a broad gravel terrace developed near the river there are outcrops of a rock composed of thin interbedded layers of blue argillite, white sandstone, and yellow-weathering impure limestone—an assemblage of rocks which, in the Cœur d'Alene district, characterizes the middle part of the Newland. The strike here is N. 50° W. and the dip 90°; to the south the strike becomes more northerly and the dip, which is to the southwest, more gentle. Above the rocks like the middle Newland, are many hundreds of feet of bluish argillite, and of greenish shaly material the yellow color of whose weathered surface indicates its calcareous nature. Similar rocks in the Cœur d'Alenes constitute the upper

part of the Newland formation. These, finally, on the top of a hill about 2,300 feet above the river, are overlain by a comparatively small thickness of green and purple beds like the typical Striped Peak.

On the east bank of the river at the ferry just below Troy there are reddish purple siliceous shales, with some thin beds of cream-colored yellow-weathering limestone. From their southwesterly dip these beds appear to be stratigraphically beneath the Newland across the river, but as their relation to any known formation was not certainly made out, their position in the sequence must be considered doubtful. To the east they show an anticlinal fold, but are separated by a broad stretch of gravel from quartzitic rocks of the Ravalli group, which are developed farther east on the road to Sylvanite.

Farther down the valley more of these calcareous shaly rocks are exposed. Some outcrops on the road a few miles west of Yaak River show greenish gray, yellow-weathering rocks with a little interbedded reddish purple shale. The strike is N. 30° W., the dip 75° SW. In the vicinity of Lenia also, east of the great fault, the rocks, which strike N. 25° W. and dip 25° W., are gray, green, and reddish-purple indurated shales, with a few beds of cream-colored limestone. It is inferred from these observations that in this vicinity the Newland may contain some beds of red shale and whitish limestone which are absent from the formation in the Cœur d'Alene district.

Near Varco's ranch, close to the Idaho-Montana boundary, are extensive exposures of typical Newland rocks dipping steeply south-southwest, and about 5 miles west some purple and green shales with a similar attitude.

Where the Kootenai Valley road crosses the Mooyie bridge gray, thick-bedded, shaly rocks, with some quartzitic bands, dipping east, were found, which doubtless belong to the Prichard formation, the Lenia fault having been crossed in an area covered with terrace gravels.

North of the valley, west of the state boundary, is a conspicuous group of high, rugged peaks of quartzite, which looks from a distance rather like the Revett than the Burke.

LOWER YAAK VALLEY.

The valley of Yaak River was examined for a few miles above and below the deserted mining town of Sylvanite, and in this portion it displays a section of some of the older formations, which in general have a southerly dip.

The country rock near Sylvanite is gray impure quartzite, thick bedded to shaly, with some argillaceous layers, dipping southeast. Up the river for at least 5 miles from the town, and an unknown dis-

tance farther, these distinctly bedded gray quartzites, with gentle dip downstream, continue. At the bridge below town the river cascades down the bedding of a blue-gray indurated sandy shale resembling the Prichard, and along the road toward Troy more typical Prichard slate is exposed. Toward Bonners Ferry no exposures are to be seen along the road until, about 3 miles from the bridge, one comes to an exposure of rock like typical Burke, striking N. 10° W. and dipping 45° W.

Anyone who visits this region for more detailed work would do well to examine the gorge of the Yaak below the falls. It should afford a good section of the Prichard, the overlying quartzites, and a part of the Newland formation.

PURCELL MOUNTAINS.

The geologic information obtained in the Purcell Mountains relates chiefly to the section along the forty-ninth parallel, which has been surveyed in detail by Daly. My observations relating to that section are stated mainly for the purpose of putting on record my conception of the correlations to be made between the strata along the boundary and the formations developed in the Cœur d'Alene district.

Mooyie Valley.—The lower part of this broad valley was traversed hastily. The slope west of the valley is apparently made up chiefly of quartzites and argillites belonging to the Prichard formation, dipping east, and interleaved with many sills of diorite. The east side of the valley is also chiefly of quartzitic rocks, including some with a purplish tinge belonging to the Ravalli group, but on this side the exposures are poor and the structure is apparently more complex than on the west side.

Vicinity of forty-ninth parallel east of Mooyie crossing.—Along the north side of Mooyie River, between the boundary and Spokane Junction, is a finely exposed section which exhibits several hundred feet of westward-dipping green and purple shales, purple and green quartzites, and argillites marked with ripple marks and sun cracks. These rocks (Daly's Kitchener quartzite?) correspond in character to the Ravalli group, but apparently comprise no white quartzite stratum corresponding to the Revett quartzite. They are underlain on the east by some very fine-grained, homogenous, blue-gray argillite, whose thickness is apparently only a few hundred feet. This is taken to belong to the stratum of blue argillite like the typical Prichard seen near Scotchman Peak, Callahan Creek, and the lower Yaak River. Below this again there are the gray quartzites, with subordinate interbedded argillite, corresponding in stratigraphic position to the lower part of the Prichard formation, which I suppose to be Daly's Creston quartzite, and these strata, with numerous dioritic sills, are exposed along the party's course to the mouth of Hawkins Creek.

From a camp in the meadows of the latter stream an excursion was made along the divide between Mooyie and Yaak rivers to Mount Ewing, several miles south of the boundary. From a point a short distance south of the boundary this ridge affords excellent exposures, but as it follows the strike it does not exhibit a great thickness of strata. It is carved from gray quartzites and argillites referred to the lower part of the Prichard formation, with heavy sills of diorite injected parallel to the bedding planes, which have produced a notable amount of contact metamorphism in the overlying sediments. These rocks all dip gently to the east.

From the longitude of this ridge eastward along Hawkins Creek and the west fork of Yaak River to the point where the latter crosses the boundary there are discontinuous exposures of rocks dipping constantly to the east, apparently in their normal sequence as laid down. These are, in order from west to east:

(1) Blue-gray argillite interbedded with gray indurated sandstone and quartzite, supposedly equivalent to the Prichard formation.

(2) Thin-bedded quartzitic rocks, whose color is light gray tinged with green and purple. These are thought to represent the lower part of the Ravalli group.

(3) Rocks like (2), but more argillaceous, and colored in rather bright tints of green and purple. These are like the typical St. Regis beds, and are presumably equivalent to them.

(4) Bluish and greenish argillaceous rocks, with abundant thin laminæ of impure limestone and calcareous argillite which weather to an ocher-yellow color. On weathered surfaces the limy layers, owing to their relative solubility, form grooves and are frequently cellular. These rocks, well exposed along the stream near where it turns across the boundary, are similar to the Newland beds and are believed to be correlative with them.

(5) Overlying these on the slope east of the bend are purple and green sun-cracked shales—some of the green material weathering yellow, as though slightly calcareous—and considerable dark blue-gray argillite. This group of strata is thought to be the equivalent of the Striped Peak formation, which it resembles in being largely constituted of purplish, sun-cracked, shaly material.

Between the west fork and the main Yaak a syncline is developed, of which a good section is afforded by an east-west ridge just south of the boundary trail. On its east limb is exposed, in reverse order, a part of the succession just described. Under the trough of supposed Striped Peak beds are some thousands of feet of thin-bedded argillaceous and calcareous rocks, comprising a bed of light-gray cellular-weathering limestone about 20 feet thick. These strata are cut by some dikes of ophitic diabase. Stratigraphically beneath them are gray-green siliceous argillites with some faintly purple bands,

such as form, in the Cœur d'Alene district, the transition between Newland ("Wallace") and St. Regis. Below, the material gradually becomes more quartzitic, and purple bands become abundant, as in the typical St. Regis beds. Rocks of this character extend down to the river, while on the opposite side and a little upstream the downward sequence is apparently continued by some purplish and greenish west-dipping quartzites resembling the Burke.

East of Yaak River observations along the boundary were continued by a traverse to the Kootenai-Yaak divide. Float and a few outcrops of noncalcareous quartzite like the Burke occur for some distance up the slope, and are succeeded by rocks like the Newland, which form the crest of the first ridge. These dip eastward, but as no considerable thickness of purple rocks seems to separate them from the Burke, they are believed to be faulted down against that formation. Along the trail for some miles they are represented by float composed largely of the ocher-yellow fragments derived from the disintegration of impure limestone. It is only on the steep slope of the second ridge crossed by the trail that thoroughly satisfactory exposures are first found. At the base of the acclivity is an outcrop of cellular-weathering, shaly, impure limestone, dipping east. About 700 feet higher, and apparently overlying this rock, are exposed about 200 feet of purple and green sun-cracked shales, also dipping east, and these are succeeded near the crest of the ridge by fine-grained, green, siliceous, banded rocks and a rather thin stratum of blue-gray argillite. Interbedded with the sediments are a few thin layers of the green porphyritic amygdaloid described on page 50. A little higher the volcanic rock, interbedded with a little green shale, forms a thick stratum, which is again overlain by fine-grained green sediments. These rocks are folded into a broad syncline, so that the stratum of green lava, tuff, and breccia, which apparently thickens somewhat from west to east, is well exposed in the cirques at the heads of the streams draining into Kootenai River.

The thickness of the green beds in the trough amounts to many hundreds of feet. Lithologically these beds are remarkably homogeneous. They are very fine grained, with a distinct lamination brought out by the differing tints of successive layers. Near the volcanic rock they have a very dark-green color, perhaps due to some admixture of chloritized volcanic material, but the bulk of them are light grayish green. In part they contain a small proportion of calcareous material in closely spaced thin laminæ, which on weathered surfaces are indicated by grooves, owing to the partial solubility of the material composing them, and are colored yellow or orange by the residual ferric oxide.

Yaak basin.—Near the ford of Yaak River below the west fork, where the main-traveled trail downstream finally crosses to the left

bank, there are bold ledges of thin-bedded impure limestone weathering with a yellow color and a cellular surface, interlaminated with bluish argillite. They dip 45° W. On the west side of the valley, about a mile below, similar rocks are exposed and are overlain conformably by a little green, thin-bedded, calcareous argillite, succeeded by green and purple siliceous shaly beds, of which a thickness of 1,000 feet was actually observed. The calcareous beds are tentatively correlated with the Newland and the purple and green beds with the Striped Peak.

East of the river in this latitude an excursion was made by Mr. MacDonald to a high isolated peak that is the most conspicuous and individual landmark in this part of the region. He notes west-dipping Newland beds for some distance from the river, then some blue-gray and purplish quartzitic material, probably belonging to the Ravalli group, with the same dip. East of these are bluish and grayish argillites, probably belonging to the Prichard formation, in which an anticline is developed. The overlying rock of which the peak is formed is flaggy gray quartzite with the character of the typical Burke. It strikes N. 40° W. and dips 40° E.

Divide at head of South Fork of Yaak River.—The ridge that parts the waters between the South Fork of Yaak River and the creeks that flow directly into the Kootenai affords a good section across the structural trend, and was traversed for a few miles east and west of the point where it is crossed by the trail from Libby to the Yaak basin.

At the pass the rocks are purple and green, siliceous, flaggy sediments dipping gently east, which are presumably to be correlated with the Striped Peak. Eastward these continue to crop out, with easterly and southerly dips, as far as a saddle, about 2 miles from the trail, which seems to mark a fault with downthrow on the west. Across the saddle the dip is west and the rock is green argillite. Continuing farther eastward, one crosses a thick stratum of interlaminated yellow-weathering limestone and argillite, and one of green argillites, the whole assemblage having the lithologic character of the Newland formation and being presumably equivalent to it. These at last are underlain by purple and green beds like the typical St. Regis, which are anticlinally folded.

West of the trail the eastward-dipping purple and green Striped Peak beds are exposed for about a mile, to the brow of a slope that leads down a deep saddle in the divide. A short distance down the slope they are underlain by green argillites, which lower down are interbedded with blue argillites and impure, yellow-weathering limestones. Intruded in these is a sill of diabase. The thickness of sediments similar to the Cœur d'Alene phase of the Newland exposed from the base of the purple beds to the bottom of the saddle is about

1,500 feet. On the west side of the saddle the succession observed east of it is repeated. The slope west of the notch, nearly parallel to the east dip of the beds, is formed largely of a comparatively thin bed of bluish argillite underlain by purple and green strata which form the crest of the next ridge. Beyond and stratigraphically beneath these appear the same calcareous sediments seen east of the notch, with apparently the same intrusive diabasic sill. It is evident that the low saddle, and perhaps in large part the valley of the South Fork, is eroded on a fault that effected a downthrow on the west of about 2,000 feet. This fault is indicated on the map.

KOOTENAI VALLEY FROM TROY TO JENNINGS.

Section between Troy and Libby.—The cuts along the railroad from Troy to the eastern border of the broad valley of Lake Creek afford discontinuous exposures of red, green, and gray shaly rocks, with some thin beds of whitish, yellow-weathering limestone. Their general strike is a little west of north and their dip nearly vertical. The conspicuous outcrop of purple and green shales just east of Lake Creek is in line of strike with the beds near the Troy ferry, which are surmised to belong to a horizon well down in the Newland or to the St. Regis formation. The beds outcropping at intervals in the lower end of Lake Creek valley show much evidence of faulting, and, as extensive faulting has occurred along the valley to the south, it is impossible at present to say with confidence to what formation these beds belong, or what is their relation to those exposed in the gorge of the Kootenai east of Lake Creek.

This gorge has cut through a great thickness of folded strata in a direction almost normal to the average strike, which is about N. 10° W. The structures observed in this section are as follows: From the mouth of the gorge the beds dip steeply east for about a mile, and then form several small folds, which at Kootenai Falls, about a mile farther, give way to a very gentle east dip. Above the falls there is developed a broad syncline, of which the western limb dips gently and the eastern rather steeply, and in this syncline the highest beds of the section are developed. Beyond is a well-exposed anticline, and farther on some minor folds are seen before the broad gravel-covered valley at Libby is reached.

East of the valley of Lake Creek the first extensive exposure shows about 600 feet of fine-grained argillite, made up of thin laminæ of green, gray, and blue material, dipping steeply east. Near the upper limit of this assemblage of beds there is a 3-foot layer of white, yellow-weathering limestone, and also a small basic dike. A space of one-fourth mile separates this outcrop from the fine exposures along the gorge proper, so that it is uncertain whether the beds of the outcrop mentioned really underlie those in the gorge or

whether, as the presence of the dike and the resemblance of the sediments to some developed at the top of the section to the east both suggest, they are separated from them by a fault. On the steep slopes of the gorge the first rocks encountered are light greenish gray argillites whose weathered surfaces are coated with a thin film of limonite. These are overlain by some purple and green beds, and these in turn by some beds of limestone with an aggregate thickness of about 30 feet, which are conspicuous in the gorge just below the main falls.

Above the falls the exposures are not so continuous on the track as they are below, for the valley becomes a little less steep sided. The large folds, however, can be clearly seen on the north side of the river. The gently inclined strata are gray-green, partly calcareous argillites, very much like those just mentioned as forming the westernmost part of the walls of the gorge. These are succeeded—apparently overlain—by purple and green beds, like the St. Regis and Striped Peak formations, and in the trough of the great syncline beyond are banded argillites, with gray, blue, and green tints, like those seen at the mouth of the gorge. The east limb of the syncline brings up rich-colored purple and green beds corresponding in a general way to those on the west limb, although the sections are not sufficiently continuous for detailed comparison.

A generalized summary of the section from the mouth of the gorge eastward, which was plotted on the large-scale map of the Great Northern Railway, is given in the following table. The assumption is made for the present that there is no faulting.

Summary of section (descending order) in gorge of Kootenai River between Troy and Libby.

	Feet.
Argillites, greenish gray and dark blue, finely laminated, not continuously exposed	4,300
Quartzites and indurated sandstones and shales, reddish purple and green	1,250
Argillites grading into sericitic quartzites, mainly green, but with purple strata interbedded	1,400
Argillites, siliceous, greenish gray, in part somewhat calcareous and weathering to a yellow color; dip flat, about	1,000
Cream-colored limestone weathering somewhat yellow, with some partings of green argillite, exposed near Kootenai Falls	30
Indurated shale and shaly limestones and quartzites, purple and gray-green, with some calcareous bands	600
Argillite, mostly greenish gray, weathering yellow as if calcareous, sun cracked and ripple marked	3,200
Argillite, purple	5
Argillite, gray-green	100
	11,885

The only place in this section where considerable faulting seems probable is just below the falls, where it is suggested by the complex deformation of the beds. A canyon here empties into the river on the north, and the section along the track is also interrupted for a few hundred feet, so that exposures are lacking at the critical point.

Between Libby and Jennings.—The section along the Great Northern Railway from Libby to Jennings affords fairly good exposures, but since its general course makes an acute angle with the prevailing northwesterly strike of the rocks it does not cross a very great thickness of strata. The structures observed in this section, which was examined by Mr. MacDonald, are an anticline and a syncline.

The rocks which it displays doubtless belong to the assemblage better exposed to the west. They are chiefly greenish-gray and green and bluish argillites, containing thin layers that weather to an ocher yellow and are evidently calcareous. Interstratified with this material are a few beds of purple argillite.

EAST SIDE OF CABINET RANGE.

GENERAL FEATURES OF TOPOGRAPHY AND GEOLOGY.

Topography.—South of Libby the Cabinet Range is high and rugged and has an abrupt, straight, and well-defined front trending about south-southeast. West of this line the spurs rise, at first rather steeply and then more gently, toward the jagged ice-carved peaks. East of it is a broad zone of comparatively low, rounded foothills, drained, within the area examined, chiefly by Libby Creek and its tributaries, but in part by headwater streams of the Fisher River system. It is near the point where this line intersects the Kootenai-Clark Fork divide that the rugged part of the Cabinet Range terminates.

The principal streams of the foothill area have a common trend about parallel to the front of the mountains, and between them are long ridges, or rounded elevations aligned in rows. Some of these hill ranges are more persistent than the streams. The one between Cherry and Libby creeks, for example, extends for some distance north of the confluence of those streams, being limited on the west by a line of broad saddles.

This marked parallelism of the topographic features depends primarily on the structure of the rocks. The general strike of the beds in this vicinity is a little west of north, and they are cut by at least one enormous fault of approximately this direction, accompanied in all probability by several others whose course is nearly the same. The location of the valleys has probably been determined in part by selective erosion of the softer strata, but it is probably due in greater degree to selective erosion along fault fissures. Both these causes seem to have had a share in the formation of the eastern front of the

range. Southwest of Libby this seems to coincide with the Snowshoe fault, but the broad valley of Cherry Creek is underlain by softer rocks than those that form the mountains on the west, and its location and character were probably in some measure influenced by this fact. Swamp Creek also is in line with a fault, of undetermined throw, traced for only a short distance, which will be described on another page. The belief, however, that faulting has influenced the topography of this area more potently than varying resistance of strata to erosion, is based not wholly on local evidence, of which there was time to gather but little. Observations extending over a large part of the region occupied by the Belt series tend to show that in general the strata of this series do not present variations in strength sufficiently marked to determine long and persistent strike valleys in the absence of faults.

General geology.—The Snowshoe fault is the principal structural feature of this part of the Cabinet Range, and has had a great effect on the areal distribution of the rocks. The rocks west of it, where they were seen, are compact fine-grained argillites, mostly greenish gray, with some calcareous material supposed to be higher in the stratigraphic column than the Striped Peak formation. East of the fault the only rocks identified belong to the Prichard and Burke formations. They are folded into an arch which has already been referred to as the Cabinet anticline. This is complete near the Yaak-Kootenai divide at the south, where the summit peaks are carved from the quartzitic rocks on its western limb. To the north, however, its axis meets the Snowshoe fault at an acute angle, and near Snowshoe only its eastern limb, composed of Burke beds alone, is present and forms the outer parts of the spurs along the face of the range. Still farther north these quartzitic rocks disappear, being perhaps entirely cut off by the fault. Beyond the point of their disappearance the steeply rising mountains are formed, from base to top, of the greenish argillites above referred to, and here the Snowshoe fault probably separates the mountains from the foothills, in which no prominent outcrops occur.

The exposures in the foothills being in general far less satisfactory than those in the mountains, but little time was spent in examining them. They seem to be in greater part of shaly rocks in which red colors prevail. Detailed examination was made in these hills only along Swamp Creek, where some pure limestones and calcareous shaly rocks, presumably Paleozoic, were found.

SECTION SOUTHWEST OF LIBBY.

A traverse was made from Libby to one of the conspicuous high peaks southwest of that place. The low, rounded foothills crossed in order to reach the mountain slope are covered with deep soil and

gravel and afford no satisfactory outcrops. The rocks composing them, judging from float, are mainly red and green shaly sediments. The lower part of the mountain slope is also covered with drift. At a height of about 6,000 feet, however, fine-grained sediments crop out, which strike N. 5° W. and dip 37° W. They have a well-developed cleavage, which strikes N. 10° E. and dips 55° W. The rock is similar to that exposed in the axis of the syncline east of Yaak River, being a light greenish gray siliceous argillite of waxy texture, whose weathered surfaces, where transverse to the bedding, exhibit closely spaced yellow stripes which are the traces of calcareous laminæ. This material is overlain by greenish-gray argillite, sun cracked, a little darker, coarser, and less slaty than that below, and not notably calcareous, which resembles the material seen east of Bull River. This forms the summit of the peak, where it dips 40° NW. Below the rock shows many minor undulations. The strata exposed on this slope are equivalent to part of the group forming Bear Peak, which is presently to be described.

SECTION EAST OF BEAR PEAK.

The ascent of Bear Peak, the most conspicuous and probably the highest summit of the Cabinet Mountains, was made by way of the canyon of Leigh Creek, which heads in the lake on the flank of the mountain. The splendid exposures encountered in this excursion made it geologically one of the most interesting, as it was scenically the most impressive, of the entire season. The section along Leigh Creek is almost identical with that seen on Snowshoe Creek, so that the first part of the following description applies equally to the vicinity of the mine.

In the lower part of the canyon the precipitous walls are of gray quartzites, which are generally more or less flaggy and sericitic, though in part fairly hard and massive. Near the mouth of the canyon they dip at a moderate angle eastward, but farther up the stream the strike becomes nearly northwest and the dip northeast, indicating approach to the crest of a northward-pitching anticline. Only the eastern half of the arch, however, is present, for about halfway up to the lake the Burke is cut off by the Snowshoe fault, whose position is marked by notches where it intersects the ridge crests on either side, and by slight gullies on the canyon walls.

Above the fault the first rocks exposed are interlaminated argillites and impure limestones, which for a short distance dip about 45° E. and then steeply to the west. A few hundred feet of rocks like those characteristic of the middle part of the Newland as developed in the Cœur d'Alenes are succeeded by rather dark gray-green siliceous argillites, finely and irregularly banded. A short distance below the lake the dip flattens rather abruptly to 25° W. For the whole mass

of strata exposed on the precipitous slopes above the lake, the strike and dip, though varying slightly, are not far from north-northeast and 30° W., respectively. The rocks west of the Snowshoe fault show no evidence of appreciable faulting. They are cut, however, by some remarkably conspicuous and persistent joints, which are vertical and strike about N. 35° W. North of the lake a small stream has eroded along one of these joints a deep, narrow cleft, down which it tumbles in a succession of cascades. The rock along the fissure shows evidence of slight movement, but the close correspondence of the strata on either side shows that there has been no appreciable displacement.

The rocks exposed on the precipitous slopes above the lake do not exhibit a wide range of lithologic variation. They are in general very fine-grained, moderately hard, argillaceous rocks, whose color is prevailingly green in various tints, more rarely bluish. There is little calcareous material except at the top of the section, where there are numerous beds of whitish, somewhat crystalline limestone a few inches to a few feet thick, whose weathered surfaces are rough and stained with ocher. Some distance down the northwest slope of the peak, whose upper portion is about parallel to the dip, there are at least 1,000 feet of strata lithologically similar to those which form the summit, and stratigraphically above them.

A summary of the section observed in this traverse, with rough estimates of the thicknesses of the subdivisions that might be discriminated on lithologic grounds, is given in the following table:

Section (descending order) from northwest side of Bear Peak to Snowshoe fault.

	Feet.
Argillites, light greenish gray, somewhat calcareous, weathered surfaces covered with limonite, with thin beds of cream-colored, somewhat crystalline, yellow-weathering limestone	1,500
Argillites, siliceous, mostly dark greenish gray but in part bluish, locally containing large crystals of pyrite	2,500
Argillites, rather light greenish gray, with thin, yellow-weathering, somewhat calcareous layers, and a few thin beds of medium-grained white quartzite	1,200
Dark gray-green banded argillite	1,500
Blue argillite, intercalated with thin layers of impure yellow-weathering limestone	500
	7,200

The correlation of these beds is problematical. The rocks that form the rugged peaks southeast of Bull Lake belong to the group described above, but the Bear Peak section exhibits some higher beds. The structure between the Snowshoe fault and the forks of Bull River is essentially synclinal, and the same horizon, namely, the top

of the beds like the Newland, is exposed near by in the lowest observed part of either limb. The arguments for considering these strata to be considerably younger than the Newland formation may be found on page 68 and need not be repeated here.

OBSERVATIONS NEAR HEAD OF FISHER RIVER AND ON VERMILION CREEK.

A canyon, whose name was not learned, which heads a few miles north of the point where the Vermilion Creek road crosses the divide, affords an impressive section of the Cabinet anticline. Along the lower part of the canyon the country rock consists of indurated sandy shales made up of dark blue-gray to white laminæ, interstratified with some beds of gray quartzite. This is succeeded by a great thickness of the blue, regularly banded argillite characteristic of the Prichard formation, and the dip gradually flattens until it becomes horizontal about halfway up the gulch, then bends down gradually to the west. The argillite is overlain again on the west flank of the anticline by quartzitic rocks, which form a group of the noblest and most rugged peaks in the Cabinet Range. On the walls of the amphitheaters carved on the eastern flanks of the peaks it is estimated that fully 4,000 feet of the quartzites were seen, yet this is not their entire thickness. These beds dip down toward the valley of Clark Fork, and presumably disappear under the Newland rocks that form the valley sides for many miles below Vermilion Creek.

The lithology of the Burke and Prichard formations in this vicinity is precisely the same as in the type localities. The main body of the Prichard, of which fully 2,000 feet are exposed here, consists mainly, as in the Cœur d'Alene district, of dark-blue argillite with only occasional thin beds of quartzite, and here as there the passage to the overlying Burke is a gradual one, marked by increasing abundance of interbedded flaggy quartzite and gradual disappearance of the bluish material. The Burke, as in the type localities, is composed of flaggy sericitic quartzites marked by shallow-water features, with gray tints that are darker toward the base of the formation. In distant views toward the high peaks of this part of the range no stratum of quartzite so pure and distinctly characterized as the Revett quartzite was definitely recognized.

In the vicinity of the Silver Butte mine, near the point where the route from the Fisher River country to Thompson Falls crosses the divide, the country rock is chiefly typical Prichard, with some Burke. The locality is about in line with the crest of the Cabinet anticline, which, however, seems to be somewhat complicated in this direction by minor folds and faults and may not be traceable to the south. On a hill across the canyon south of Silver Butte a fault was seen

which brings westward-dipping Burke underlain by Prichard against westward-dipping Prichard. The course of the fissure is about north-northwest; the downthrow, amounting to fully 2,000 feet, is on the east. The fault is not conspicuous, and was traced for only a short distance. The Silver Butte vein has no connection with the north-northwest faults, its strike being about N. 60° W. and its dip 30° S. In the vicinity of the mine the strike and dip of the strata are both highly variable.

On Vermilion Creek and its west fork, down which the road descends, the sedimentary rocks exposed are dark argillites with some beds of indurated sandstone, belonging to the Prichard formation and having its typical aspect. The dip is generally steep and to the west, but a steep east dip was observed a few miles below the pass. On the lower part of the creek basic dikes or sheets in the steeply inclined strata were seen, and the syenitic mass described on page 46. The sedimentary rocks near the mouth of the canyon were not examined, and the location of the Snowshoe fault, as well as its relation to the syenite, is drawn on the map by conjecture. It was expected that the fault would be found to pass west of the mouth of the stream, but observations made a little farther east along the valley and presently to be discussed (see p. 83), indicated that this was not the case.

SWAMP CREEK.

Near the middle of its course the valley of Swamp Creek, mostly rather flat bottomed, becomes constricted for a mile or so by a projection from the west side. At the northern end of this constricted portion there is a bridge, which, in order that the locality may be identified by future observers, may serve as a point of reference in the following description.

For a few miles below the bridge, limestones, forming a thicker and purer mass than any found in the known Algonkian strata of this region, are exposed along the road, chiefly on the east side of the creek, but also, for some distance below the bridge, on the west side. This heavy limestone, lithologically, is very light colored on weathered surfaces, but gray to drab on fresh fracture. It is rather fine grained and somewhat crystalline. Rubbed with a hammer it gives off a fetid odor. It is locally somewhat shaly, though without clay partings of appreciable thickness, but some of it is fairly thick bedded. The only traces of organisms found in this stratum consist of tubular bodies that suggest filled worm borings.

The most prominent exposure of this limestone occurs just west of the bridge. Here a steep spur gives a cross section of several hundred feet of the rock, striking about north-northwest and dipping steeply east. On the west the outcrop of limestone abruptly termi-

nates at a little defile which is in line with the valley, and is succeeded by reddish-purple and green, indurated, sandy shales, with a few thin beds of yellow-weathering limestone that is pink on fresh fracture. These strata have approximately the same attitude as the thick stratum of limestone, but the abruptness with which the latter is cut off, and the depression of the surface along the contact, strongly suggest a fault, which, if it exists, probably had some influence in determining the location of the valley.

East of the bridge a traverse was made for a long distance up the slope. At the base some blue-gray and red argillite was found, and east of it a vertical bed of limestone similar to that described above, but somewhat thinner. A short distance down the stream the two beds of limestone seem to merge, perhaps through faulting, of which brecciation in the rocks gives some indication. On the slope above the limestone, and apparently deposited conformably upon it, is a great thickness of argillaceous beds, which dip east for perhaps a mile, then west. Near the base of the slope the material consists largely of a peculiar, very fine-grained, cherty shale, which is finely banded in dark blue-gray and olive-green, or in dark blue-gray and white. For some distance above the prevailing rock is green argillite, which is followed by red and green, indurated, more or less sandy shales. Near the top of the section some thin beds of the yellow-weathering limestone, interstratified with red beds as it is west of the creek, are found.

On the east side of the valley a little farther south similar beds were examined by Mr. MacDonald, who found in the limestone some imperfect fossils that could not be specifically determined but have a Paleozoic aspect.

CLARK FORK-FLATHEAD VALLEY FROM VERMILION CREEK TO DIXON.

Vermilion Creek to Thompson.—At the place where Deep Creek emerges from its canyon, whence it flows through a deep trench in the broad terraces to Clark Fork, the mountain slope is formed of Prichard slate which strikes N. 10° W. and dips 60° W. On the terrace abundant fragments of the yellow decomposed material that has often proved to be an indication of the presence of calcareous Newland rocks beneath the surface suggested that the edge of the valley was coincident with a great fault, but nothing certainly in place was seen. Within a few miles to the southeast, however, clear evidence of such a fault was found. The river above Deep Creek swings in a great bow, convex to the east, and has almost completely cut away its terraces for a little distance along the east side, so that the road has to rise far above its usual level to find safe ground. At the south end of the bow a high northwesterly facing bluff extending out from the

mountain side exposes a section of fine-grained purple and green argillites, somewhat crushed and disturbed, but with a general eastward dip. These probably represent the upper part of the St. Regis formation. The slope of the valley side within a few yards of the easternmost exposures of these beds shows gray quartzite that is judged from its lithologic character and its position with reference to the beds on Deep Creek to be near the base of the Burke formation.

This fault contact was thought to represent the continuation of the Snowshoe fissure, whose course is represented on the map accordingly. The mapping, however, involves much assumption in that the fault is drawn for a long distance through country that has not been traversed. The fault along Clark Fork valley has a slightly more northwesterly course than has the Snowshoe fault, where it was first observed, and the two may intersect at the edge of the valley west of Vermilion Creek. It is also possible that the Snowshoe fault may die out before reaching the valley, but its throw is so great that it would be likely to persist across the range.

Little time was spent in detailed observations on the side of the broad valley about Thompson Falls, but some notes concerning the stratigraphy and structure in this vicinity may be worth recording.

The slopes north and east of the expanded portion of the valley in which the town is situated are carved from yellow-weathering Newland rocks which, with some underlying beds, are well exposed on the sides of a canyon that drains into the river near the railroad bridge below town. At the base of the mountain front, north of the creek, the lowest beds exposed are gray sericitic quartzites, like typical Burke, dipping north-northeast. Above them is some hard, fairly pure quartzite supposed to correspond to the Revett, but only about 200 feet thick. This is overlain by light purplish-gray and greenish-gray flaggy quartzites and siliceous argillites, like the lower St. Regis beds, which have a very distinct cleavage that strikes N. 10° W. and dips 50° W. Beyond a saddle that probably marks a small fault there are more of these beds, striking more nearly north-northwest and standing about vertical, and farther on are the Newland beds which have a decreasing eastward dip. It is believed that these beds will prove to be separated by a fault from the older, westward-dipping strata that form the valley side farther north. Indeed, the next large canyon in that direction shows near its mouth a large exposure of dark-colored west-dipping strata which appear from a distance like Prichard, and farther up the canyon is exposed a light-colored rock which forms a heavy talus and may well be quartzite of the Burke formation or the Revett quartzite that has been faulted down.

Thompson Falls probably owe their origin to Clark Fork having encountered, in sinking down through the old gravel deposits, a

bench projecting from the southwest side of the valley. When the stream reached the level of the rock its down-cutting action was locally retarded, and continued rapid erosion in the gravels below the bend soon initiated a cascade, whose recession has formed a shallow gorge about a mile long. Along the east side of this gorge is exposed a succession of strata that have a gentle northerly dip. The uppermost part of the section consists of gray-green, yellow-weathering, calcareous argillite, like lower Newland, which is underlain by several hundred feet of purple and green beds having the lithologic aspect of the St. Regis formation. These are underlain in turn, without the intervention of any strata resembling the quartzite of the Burke or the Revett, by blue and white shaly argillite like the upper part of the Prichard, well exposed in the immediate vicinity of the falls. These beds probably form a lens of somewhat limited distribution, for nowhere else have similar blue argillites been found at this horizon.

Prospect Creek.—Prospect Creek, which flows in a rather broad-bottomed valley whose steep sides afford good exposures, has been reconnoitered from its mouth to the Cœur d'Alene district, where it originates. For a short distance from the river it flows through rocks resembling the Burke, which are anticlinally folded. These are succeeded by typical calcareous Newland beds, dipping east, the contact, which is marked by a line of saddles, being due to a fault. Whether or not this is a still further continuation of the Snowshoe fault, as seems quite possible, could not be proved without more detailed examination and exact mapping, if indeed the drawing of the fault across the wide alluvium-filled valley would in any case be justified.

Upstream from this fault contact a good section of rocks, dipping steeply eastward, is exposed. A considerable thickness of Newland is succeeded by purple and green St. Regis beds, which grade into hard, white Revett quartzite, exposed about 7½ miles up from the river. Farther on, these pass gradually into flaggy sericitic quartzites of the Burke formation. In the vicinity of the mines, about 9 miles above the mouth of the creek, the country rock is Burke and Prichard, showing rather complex deformation. Beyond, the Prichard, with a broadly anticlinal structure, is extensively exposed, and within a few miles from the boundary of the Cœur d'Alene district it is seen dipping westward under the Burke formation.

Gorge between Thompson and Plains.—Between the broad vales in which Thompson and Plains are situated the river flows in a steep-sided canyon, which displays an excellent transverse section of folded strata belonging to the Ravalli group and the Newland formation. The structure and general stratigraphy of this section will be de-

scribed, and then a comparison will be made between the beds exposed here and the corresponding beds of the Cœur d'Alene district.

Going eastward through the canyon, whose west end is near the mouth of Thompson River, one crosses successively an anticline and a syncline. The steep spur that forms the west portal of Thompson River canyon is carved from westward-dipping rocks; these were not examined at close range, but the upper portion, which is much stained with ocher, doubtless consists of calcareous Newland beds, while the lower portion appears to be more quartzitic and presumably represents the St. Regis formation. A cut not far beyond this stream shows flaggy to rather thick-bedded, somewhat sericitic, gray quartzites, with a strike of N. 20° E. and a dip of 40° W., and these form the walls of the Clark Fork canyon for several miles eastward. In this direction the dip soon becomes lower and more northerly on the north side of the river, but is apparently southerly on the south side. About a mile west of Eddy the strata bend down rather sharply from a nearly horizontal position, and near the station dip about 45° NE. The flexure is well exposed in section on the south side of the river. On that side there is some suggestion of faulting parallel to the course of the stream, for the upper part of the slope is of soft rocks that resemble at a distance the Newland beds, and these appear to have been dropped down a little behind the quartzites.

Three miles east of Eddy a prominent spur affords a good exposure of purple and green beds, corresponding to the St. Regis formation, which strike N. 10° W. and dip steeply east, and these are succeeded by a thick accumulation of fine-grained sediments which are in large part calcareous and weather in general to a clay-yellow color. These sediments, from their character and position, evidently belong to the Newland formation. They maintain a rather steep east dip for about a mile and a quarter, then flatten rather abruptly. After continuing in an almost horizontal position for more than a mile and a half, they abruptly turn up again to an inclination of 55° W., thus completing a steep-sided, flat-bottomed syncline. The steep westward-dipping calcareous beds are exposed for half a mile farther eastward, until the exposure is interrupted by the rather wide valley of a creek that flows into the river from the north. Beyond, the sides of the canyon are lower and more gentle, but for 3 miles along the railroad track there are numerous exposures, appearing to be practically continuous on the slope to the north, of grayish quartzites, whose strike varies from N. 20° W. to N. 30° E., and which dip regularly westward at angles ranging from 20° to 55°.

The beds stratigraphically lowest in the section described in the preceding paragraphs closely resemble the Burke formation as exposed in the eastern part of the Cœur d'Alene district. They consist of more or less flaggy siliceous rocks, medium to fine grained,

whose color is a light gray, slightly tinged with green or purple. They are, on the whole, rather thicker bedded than the material that represents the formation near Burke, and, as in the sections north and east of Thompson Pass, comprise a good deal of rather hard, finely banded, purple quartzite.

The Revett quartzite of the Cœur d'Alene district seems to be represented by beds of fairly pure greenish-white quartzite, rather unsatisfactorily exposed in scattered outcrops just east of Eddy. This material is not as homogeneous as the typical Revett quartzite, however, and does not constitute, as that formation does in the Cœur d'Alene district, a distinct and heavy stratum sufficiently differentiated from those above and below to be readily recognized in distant views. In this vicinity it is doubtful whether it could be mapped separately from the Burke formation.

The beds above the light-colored quartzitic rocks, closely examined only at the locality 3 miles east of Eddy before mentioned, are lithologically identical with the typical St. Regis beds as exposed in Military Gulch in the Cœur d'Alene district. They are indurated flaggy sandstones and shales, which exhibit the sun cracks and ripple marks and the bright green and purple tints characteristic of that formation.

As in other localities, these green and purple beds pass gradually into the overlying Newland formation, whose basal portion is green argillite. This phase, however, seems hardly as thick here as in the Cœur d'Alene district. The bulk of the material exposed in this section consists of grayish, more or less calcareous argillites intercalated with thin beds of impure limestone. The argillites on fresh fracture are mostly dark bluish gray and more or less distinctly banded, but as they contain ferruginous carbonates they weather in drab or yellow tints. The banded phases exhibit crumpling, and the more homogeneous phases have a cleavage that was seen in one place to strike about north-south and to dip west. The limestone is chiefly of a bluish tint and commonly weathers yellow. A rock somewhat different from any seen in the Cœur d'Alene district is exposed near the east limit of the exposure. It is a gray, drab-weathering, calcareous shale which contains numerous rudely ellipsoidal nodular bodies about one-half inch to 1 inch in diameter, of very fine-grained, nearly black limestone, which is more soluble than the matrix and weathers to a light-gray color.

The beds of this section do not comprise, so far as noted, any of the layers of calcareous quartzite that are characteristic of the middle part of the Newland ("Wallace") as developed in the Cœur d'Alene district. On the whole they are somewhat finer grained and more calcareous than the Cœur d'Alene phase of the Newland and more closely resembles the corresponding beds of the Philipsburg district in Montana.

Plains to Dixon.—From a point a few miles southeast of Plains the Clark Fork and Flathead River flow in a canyon with steep rocky sides. About 15 miles farther upstream the valley becomes very open and the hills on either side are low, but the outcrops are still fairly numerous. Throughout this distance the sedimentary rocks exposed along the railroad are dark, mostly bluish-gray, quartzitic and argillaceous sediments, correlated with the Prichard formation. They are cut by a large number of the dioritic dikes or sheets whose petrographic character is described on page 49. The sediments have suffered complex deformation. The strikes and dips along the track are very variable, and when platted indicate that the folds are pitching ones. The greatest fold noted is an anticline between Plains and Paradise Spring, indicated by the dip symbols on the map. No positive evidence of extensive faulting was observed, but in places the attitude of the beds changes so abruptly as to suggest that some faulting has occurred.

A feature of some local interest is Paradise Spring, situated on Missoula River about 3 miles from its mouth. It is a sulphur spring, with a temperature of about 100° F., which issues from the talus at the foot of a large outcrop of diorite, intrusive in the Prichard rocks.

The lithologic character of the sediments in this section is very similar to that of the Prichard formation as developed in the type locality. The beds consist of regularly banded blue-gray argillites with some gray siliceous indurated sandstone. Their weathered outcrops, like those of the typical Prichard, have a rather somber hue, and are somewhat stained with dark reddish-brown ferric oxide. On the whole, however, the beds are of a lighter gray color and slightly more siliceous than the corresponding strata in the Cœur d'Alene district, although not as arenaceous as the Prichard formation along the boundary and in the western part of the Cabinet Range.

NORTH SIDE OF MISSOULA VALLEY.

Vicinity of Lothrop.—The high, sparsely timbered hill across the river and north from the town of Lothrop shows on its upper portion a considerable thickness of light-colored beds dipping gently to the northwest. In ascending the hill from the southeast one passes over the following apparently conformable strata in order of superposition:

(1) Olive-green, more or less arenaceous shale; thickness, 1,200 feet. Base not seen.

(2) Deep-red siliceous shale, apparently grading upward into red banded quartzite, which grades into pinkish-white quartzite; total thickness, about 250 feet. A little saddle without exposures beyond.

(3) Limestone, gray, rather fine grained, distinctly bedded, containing black fragments of crustacean tests and showing vermicular bodies on weathered surfaces; thickness, about 1,500 feet. Top removed by erosion.

West of the summit these beds abut against a fault plane which, from the course of its trace on the surface for the short distance it was followed, appears to strike about north-northwest and to dip east.

Mr. Walcott, after seeing specimens of the limestone and hearing its relations described, expressed[a] the opinion that it was the middle Cambrian limestone, which forms a thick mass in the Mission Range to the east. The quartzite he considers as presumably representing the Cambrian Flathead quartzite, and the red and green shale beneath as Algonkian.

At a point a mile farther west a narrow strip of similar limestone, dipping south, is exposed on the brow of the steep slope overlooking the valley. Its stratigraphic relations, however, are here obscure, for the rock north of it is not exposed, and a fault which limits its outcrop on the southwest has given rise to a remarkably coarse limestone breccia forming conspicuous crags, whence great blocks have rolled down the slope.

Lothrop to Iron Mountain.—The rocks seen along this portion of the route are mainly argillites and quartzites, resembling the sediments of the Cœur d'Alene district in a broad way, yet sufficiently different from the formations that have been studied in detail to prevent definite correlations on lithologic grounds. Among the most abundant and conspicuous rocks developed in Missoula Valley are argillites and flaggy quartzite of a bright maroon color, which resemble the beds that immediately overlie the Newland east of Clarkfork, and may be equivalent to the Striped Peak formation. The presence of thick strata of supposedly Paleozoic limestone, of which two exposures in addition to those already described were seen, tends to indicate that the Algonkian rocks exposed in this valley belong chiefly to the upper part of the system.

The strike is prevailingly between west and north-northwest, and the dips, which are not usually higher than 45°, are in greater part to the south and west. Although little evidence of faulting was obtained, the frequency with which the boundaries between groups of strata differing in lithologic character coincide with ravines suggests that the country may be considerably faulted, and makes it impossible in many places to ascertain, without detailed examination, the relative age of masses exposed within a short distance of one another.

As a possible aid to future work the most extensive exposures will be described briefly.

Four miles northwest of Lothrop there is a good exposure of several hundred feet of deep-red shaly and quartzitic beds intercalated with some green layers, dipping very gently south. Higher

[a] Orally.

in the succession the red material gradually disappears, while the green argillite, becoming somewhat calcareous, assumes the aspect of typical lower Newland. Some 300 feet of these green beds are overlain by dark limy slate and impure shaly limestone, very similar to some of the material in the syncline of Newland rocks east of Eddy. On lithologic grounds this assemblage of strata might well be correlated with the upper part of the St. Regis and the lower part of the Newland formation, but the fact that the deep-red color of the lower beds is decidedly different from the more subdued purple tint characteristic of the St. Regis formation wherever it has been certainly identified, together with the proximity of probable Paleozoic limestone, weakens the force of this lithologic evidence, which is not corroborated by evidence of other kinds.

About half-way between Lothrop and Quartz there is a bluff on the north side of the river, about 1,500 feet high, which exposes a very striking section of shaly beds, mostly deep red, with some green layers. They dip gently west, so that some reddish-purple quartzites, exposed a little farther down the valley and also dipping west, apparently overlie them. These quartzites dip toward a cliff composed of a light greenish gray banded, indurated argillaceous sandstone with some finer-grained layers that exhibit mud cracks. The weathered surface shows differential etching of the laminæ and is slightly stained with yellow limonite, both of which facts indicate that the rock contains carbonates. These beds are somewhat unlike any seen elsewhere in the region. They resemble certain phases of the lower Newland, but are coarser in texture. It seems most probable that they belong to Walcott's Camp Creek "series."

Opposite Quartz there are exposures of light-colored calcareous shale, dipping north, which are succeeded abruptly by red shaly quartzite, and as both rocks are brecciated the plane of contact is probably a fault. Beyond, for about one-half mile, there are shaly rocks dipping north. These are mostly red, but comprise green layers and patches, and a change from green to red in the same layer is not infrequently to be observed. North of this exposure and separated from it by a gully there appears an outcrop of gray, distinctly bedded limestone, dipping steeply south at first, then 45° N., which is somewhat brecciated and probably faulted against the red beds. Several hundred feet of this limestone is exposed; then some red quartzite, whose relation to it was not ascertained and which may be faulted up; then a steep cliff, about 500 feet high, of gray limestone, which appears to overlie some red quartzite that dips toward it near the base. This relation and the lithologic character of the limestone make it highly probable that it is the same stratum that is exposed at Lothrop.

About halfway between Quartz and Iron Mountain there are good exposures of several hundred feet of gently inclined greenish-gray, flaggy, sericitic quartzite somewhat similar to the Burke beds. Beyond, in unknown relation to this rock, is some red flaggy quartzite striking N. 40° E. and dipping 40° SE. About 3 miles southeast of Iron Mountain there is encountered the border of an extensive area of shaly calcareous rocks like the Newland beds developed east of Eddy. These show considerable folding and a variable strike. In the finer-grained material distinct cleavage is developed, whose strike and dip at one place are N. 75° E. and 75° N., and at another N. 10° W. and 75° W. These rocks continue along the valley for an unknown distance northwest of Iron Mountain.

Iron Mountain to Paradise Spring.—That the rocks at Iron Mountain belong to the Newland formation is proved by their relation to underlying strata exposed on the ridge north. The roads and trails across this ridge, built for the Iron Mountain mine (described on p. 107) afford opportunity to observe a thick, well-exposed section of all the strata included between a horizon far above the base of the Newland and one some thousands of feet below the top of the Prichard.

In the canyon below the Iron Mountain mine the rocks consist almost entirely of interbedded calcareous argillites and impure limestones that have been considerably folded. About one-half mile below the mill, however, there are some exposures of a light-greenish quartzitic rock, dipping north, which may belong to the St. Regis formation. In the vicinity of the mine there are extensive outcrops of greenish and bluish distinctly calcareous rocks. They dip northeast, first at a moderate angle, then farther on very steeply, and are almost vertical for a considerable distance along the road. A zone of complex folding succeeds the vertical dip and is followed in turn by a continuously southward dip, which persists to a point beyond Paradise Spring.

About one-half mile south of the summit the distinctly limy beds are succeeded by a small thickness of noncalcareous green argillite, which is underlain by richly colored purple and green beds, like the typical St. Regis. By gradual transition these pass over into somewhat thicker bedded and more quartzitic rocks, only faintly tinged with green and purple, exposed near the summit and a little beyond. There is here no hard white quartzite like the Revett quartzite. Many hundreds of feet of more or less flaggy beds corresponding to the Burke formation are exposed on the northern slope and are underlain by blue argillites and graywacke of the Prichard formation, of which probably some 5,000 feet are crossed before reaching Paradise Spring.

CHAPTER IV.

NOTES ON THE ECONOMIC GEOLOGY.

By D. F. MacDonald.[a]

INTRODUCTORY STATEMENT.

The examination of the mineral resources of the region traversed was but a secondary object of the reconnaissance. Only such mines and prospects therefore were visited as lay near the main route of travel, and none of these were exhaustively studied. The material thus hastily gathered could not furnish a basis for anything more than brief and general descriptions, but as virtually nothing regarding the ore deposits of this extensive tract had been published prior to our visit, even a very incomplete account has been considered worth putting on record.

The following notes are substantially a reprint of a paper published in 1907.[b] It was expected that some account of development subsequent to 1905 might be prepared from data furnished by mining men to those engaged in gathering for the Survey the statistics of mineral production, and the publication of this paper has been somewhat delayed in order that such data might be used. Unfortunately, little information of this kind has been acquired. In the time that has elapsed since our visit no production has been reported from the properties visited by us, except from one mine on Lake Pend Oreille, which has produced a small quantity of rich silver ore. Some of the most promising mines of the region seem to have lain idle because of litigation.

The metalliferous deposits observed in the course of this reconnaissance are mostly fissure veins. Not only in this respect, but also in prevailing composition and attitude, they exhibit some resemblance

[a] Since, owing to space restrictions, it was necessary that the originally published outline of this chapter be very brief, it has been somewhat expanded in the absence of Mr. MacDonald by Mr. Calkins, who is entirely responsible for the descriptions of the mines on Callahan Creek, those at the head of Fisher River, and those in Missoula Valley.—Editor.

[b] Contributions to economic geology, 1906: Bull. U. S. Geol. Survey No. 285, 1907, pp. 41–52.

to the famous deposits of the Cœur d'Alene district. As in that district, so also in the region to the north and east of it, the most important economic mineral is argentiferous galena, and although deposits of copper, gold, silver, and zinc occur, the lead-silver deposits appear to give most promise of future productivity. The trend of the veins naturally varies considerably more in this wide territory than within the relatively narrow limits of the Cœur d'Alene district, where most of the veins have a trend near west-northwest; but for the ore-bearing fissures as well as for the major faults there is a decided preponderance of northwesterly over northeasterly strikes. Dips to the north and east seem to be about as numerous as those to the south and west. The incomplete data at hand also tend to indicate that, as in the Cœur d'Alene district, galena generally occurs in steep fissures, related to, though rarely coinciding with, the major faults. This mineral appears to show, although in less marked degree than in the Cœur d'Alenes, a preference for the quartzitic sediments of the Ravalli group as country rock. The parallel is further carried out by the auriferous deposits, which, in the region as a whole, seem in general to develop chiefly in the Prichard formation, and to lie for the most part in relatively flat fissures which are more nearly parallel to the bedding than to the steep faults of large throw.

Deposits that have been prospected or exploited are more numerous in the western part of the region, where intrusive igneous rocks occupy a considerable part of the surface, than in the central and eastern parts, where igneous rocks are relatively rare, and one more instance thus appears to be afforded of that general relationship between ore deposition and igneous intrusion whose existence modern studies tend to establish more and more firmly.[a] But, on the other hand, the region contains relatively few deposits having any obvious and intimate relation to intrusive masses, and several of its more important mines, as the Snowshoe, south of Libby, and the Iron Mountain, north of Missoula River, are many miles from any extensive area of igneous rock. These facts, however, can not be considered as proving that any of the ore deposits of the region are totally independent of igneous agencies. Ransome[b] has pointed out in discussing the origin of the Cœur d'Alene ores that the lack of obvious relationship between the ore deposits and the areas where igneous rocks crop out does not prove their independence, since it is possible that the hot ascending solutions which deposited the fissure fillings may have derived their heat, if not their substance, from magma chambers lying at a relatively small dis-

[a] See Lindgren, Waldemar, Present tendencies in the study of ore deposits: Econ. Geology, vol. 2, 1907, p. 743.

[b] Ransome, F. L., and Calkins, F. C., The geology and ore deposits of the Cœur d'Alene district, Idaho: Prof. Paper U. S. Geol. Survey No. 62, 1908, pp. 135–139.

tance beneath the surface. Similar considerations may apply, although possibly with diminished force, to the broad region dealt with in this chapter. Although batholithic intrusions occupy a relatively small area in the central and eastern parts of the region, dikes and sheets of igneous rock occur there in considerable number.

A few deposits of a type allied to contact-metamorphic deposits were seen.

The only noteworthy nonmetallic mineral product of the region is lime, which is produced commercially by a single plant situated on the shore of Lake Pend Oreille.

It will be convenient to describe the mineral resources by localities, in the order in which they were visited.

DESCRIPTIONS BY LOCALITIES.

PINE CREEK DISTRICT.

General features.—Pine Creek is about 6 miles west of the Bunker Hill and Sullivan and the Last Chance mines of the Cœur d'Alene district. It flows in a northerly direction into Cœur d'Alene River and drains a large wooded basin, which lies partly within the area shown in the Cœur d'Alene special map and described in Professional Paper 62 (just cited), but mostly to the west of it.

The country rock of the mines visited on this stream is Prichard slate, and the veins are in fissures, many of which have had their walls partly replaced by vein material. The vein filling is white quartz and crushed country rock, the whole somewhat iron stained. The ore is a silver-bearing galena associated with zinc and some siderite and pyrite. The silver-lead values are low, and transportation charges are so high at present that mining for zinc, of which some of the ore contains as much as 20 or 30 per cent, is not profitable. The weathered zone of these veins was found to be fairly rich in silver and lead carbonates to a slight depth, but the base ore was soon reached and development work was then usually suspended. Although much exploration work has been done in the district and considerable bodies of low-grade silver-lead-zinc ore have been found, very little mining activity was evident at the time of visit.

Mines and prospects.—The Anderson group, 3 miles from the mouth of Pine Creek, has a few tons of rich-looking ore on the dump. The development work done there consists of a 60-foot adit and a 20-foot winze.

At the King property, a mile south of the Anderson property, a few tons of ore have been extracted from an 85-foot adit.

At the Douglas, 6 miles south of the King, a considerable amount of development work has been done. Three hundred tons of ore are

on the dump and about 10,000 tons are said to be in sight. The ore, which seems to be a fine-grained galena, is peculiar in that it carries, as reported, almost 30 per cent of zinc.

The Surprise, on another branch of Pine Creek, is about 2 miles southeast of the Douglas. A 450-foot crosscut adit taps the vein at considerable depth. It is said to give an average assay of 31 per cent lead, 30 per cent zinc, and 10 ounces of silver to the ton.

The Nevada Stuart is just across the creek from the Surprise, and is on the same northwest-southeast lead. A 300-foot adit constitutes the development work.

The Nabob, on Stone Creek, a tributary of Pine Creek, expected to ship four carloads of ore in 1905.

Outlook for the district.—The mining future of Pine Creek depends on the discovery of some satisfactory treatment for saving and separating the silver, lead, and zinc values of the ores. Such treatment should enable the district to become an important producer, but under present conditions development on a large scale can hardly be expected from it as a whole. It is possible, however, that ore bodies may be discovered which contain less zinc and a greater amount of silver and lead.

LAKE PEND OREILLE DISTRICT.

VICINITY OF LAKEVIEW.

General features.—The little town of Lakeview is built on a terrace at the southeast end of Lake Pend Oreille, at the mouth of a stream that drains a mountainous basin, which is perhaps 50 square miles in area. Although extremely quiet now, it once gave promise of being a most active mining center.

In October, 1888, Messrs. Frederic A. Webber and S. P. Donnely came across from Eagle Creek, in the Cœur d'Alenes, on a prospecting trip. They made a discovery and went back for supplies. Despite their attempt to maintain secrecy a suspicion of their find got abroad, and on their return many others followed them back across the mountains. That fall and winter more than 2,000 people went into the new district and founded the town of Chloride, about 5 miles up the valley from Lakeview, of which there are now but a few tumbledown shanties remaining. The boom lasted about a year, and then the stampede element drifted away and only those who had faith in the district remained and continued systematic development of their holdings.

The country rocks of this district are chiefly of the Newland formation, but comprise some quartzites, limestones, and slates of earlier and later age. They are cut by a number of faults having

various directions. A few miles to the west, and also to the north, the sediments are invaded by monzonitic intrusions.

Mines and prospects.—The Webber group of claims lies about 6 miles south of Lakeview, from which place it is reached by wagon road. The vein is in a fault fissure whose walls have been somewhat replaced by vein material. The fissure runs about east and west, and gives evidence of a considerable displacement. It is associated with a diabasic dike and cuts a country rock of shale of the Newland formation.

On the surface in the weathered zone the ore carried free silver to a reported value of about 400 ounces per ton. This led to its acquisition by a company and the installation of a complete free-milling plant. Soon, however, the lead and silver appeared in the sulphide form, and the values could not be saved by such a process. Some shipments were then made to a smelter, but the ores were not of high enough grade to return a profit, and accordingly operations at the mine and mill were suspended. It is reported to have undergone some development, however, since our visit.

The Keep Cool group adjoins the Webber property on the west and appears to be on the same vein. A section of the vein here shows a rather wide zone of breccia, gouge, and quartz carrying considerable galena and striking about N. 75° W., with a dip of 75° S.

The Conjecture property lies a mile below the Webber on the same creek. The country rock, vein, and ore are practically the same as those of the Keep Cool and Webber mines. A free-milling plant was used for the treatment of the rich surface ores.

The Hidden Treasure claim is located on a fissure in the supposedly Paleozoic limestone near a fault of considerable displacement. It is being worked by an open cut which reveals galena of good quality. The Venezuela and Silver Chord had not produced any ore at the time of visit, and have not reported any production since then.

Production.—The following table shows the estimated amount and value of ore shipped from the district:

Ore shipped from the Lakeview district.[a]

Name.	Tons shipped.	Value per ton.	Remarks.
Webber group	Concentrates, 2,000; crude ore, 11,000; now on dump, 6,000.	Lead, $2; gold, $1.50; silver, 24 to 50 ounces.	Idle for some time; hope to resume work when new smelter is built at Sandpoint.
Keep Cool	To the value of about $15,000.		Not working.
Conjecture	To the value of about $70,000.		Do.
Vulcan	50		Do.
Hidden Treasure	50; on dump, 50	Average assay, $40	One man getting out ore.

[a] This table is based on data kindly furnished by Mr. F. A. Webber.

Outlook.—This district has been proved to contain considerable low-grade silver-lead ore. Under present conditions the operation of the many small properties of the district would be expensive. Cheap production is the problem to be solved in this field. Consolidation of interests and work on a large scale would seem to be the best means of attaining that result, and would very probably produce some good dividend-paying properties. The new smelter at Sandpoint should ultimately furnish a better market for the ores than has hitherto been available, and materially encourage further work.

LIME PLANT AT SQUAW BAY.

A plant of four kilns at Squaw Bay, a few miles from Lakeview, is operated by the Washington Brick and Lime Company, of Spokane. It had been running fifteen months at the time of our visit and was turning out about 75 barrels of lime a day. This product is shipped on scows to Hope, on the Northern Pacific, and thence to its destination by rail.

A large mass of fairly pure crystalline limestone of uncertain age (see p. 62) occurs close by, and a quarry in this deposit now furnishes all the rock burned in the kilns. This deposit, together with others of the same nature which are found on the shores near Lakeview, will probably answer all demands made upon them for an indefinitely long period.

WESTERN SHORE.

There has been considerable prospecting and some productive mining on the western shore of Lake Pend Oreille. The most promising developments are in the vicinity of Blacktail Point.

The rocks of the western shore are pre-Cambrian sediments of the Belt series. Monzonitic rocks intrusive into them lie to the south and west, and the older sedimentary formations, which are exposed along the northern part of the shore, are cut by many basic dikes and sills. Structurally this vicinity is characterized by the presence of several large faults which have a northwestwardly trend and a downthrow on the southwest side.

The most important property is apparently that near Blacktail Point, owned in 1905 by J. A. Browne. The development work done on this property in 1905 consisted of a tunnel over 1,000 feet long and some short drifts. Extensive improvements, including an electric generating plant to be run by steam power, and several substantial buildings, had also been made.

The mine is situated on the west slope of a valley having a trend of about N. 30° W. This valley is evidently situated on a fault line, for although the Newland rocks west of it, which form the country

rock of the mine, have a general easterly dip, the rocks east of it are the older quartzitic sediments belonging to the Ravalli group, and at the shore line, where they are exposed within a few rods of the Newland formation, they exhibit considerable fracture and contortion.

The tunnel crosscuts the strata, which, although their general dip is eastward, are affected by some minor folds. Several small faults which throw veins parallel to the bedding were noted, the largest dislocation observed being about 4 feet. About 850 feet in from the portal there is a strong fault fissure whose course is N. 10° W. and whose dip is 80° E. Two slips with a direction N. 30° W. were also noted. The principal vein of the mine, near the end of the tunnel, strikes a little east of north and dips steeply east.

The valuable minerals in the vein are galena and tetrahedrite, the latter being present in unusually large proportion. Associated with these are quartz, pyrite, and siderite. Some specimens clearly exhibit a replacement of wall rock by vein matter.

No shipments of ore had been made for some time previous to our visit. The ore was said to be rich in silver, but no assay figures were obtainable.

The Blackbird mine, owned by the Blacktail Mountain Mining Company, reported the production of some rich silver ore in 1906, but the amount is not indicated.

EASTERN SHORE.

General conditions.—As the Lakeview district began to decline the many prospectors it had attracted gradually scattered over the surrounding mountains. The result was that a great number of claims were staked on the eastern shore of Lake Pend Oreille. Many of these were abandoned, but a few are still being developed for their gold content; others are held as future producers of silver and lead. Perhaps the most promising, however, are those which are being developed for their copper values. In spite of the lack of concentrated development work, the district gives some promise as a prospecting field and may yet develop shipping properties.

Prospects.—The Green Monarch, developed by a tunnel driven into the steep, rocky bluff which forms the southern shore of the east arm of the lake, shows a vein of low-grade copper ore consisting chiefly of chalcopyrite with a little copper carbonate in a gangue of quartz. The country rock is impure quartzite of the Ravalli group; the vein strikes N. 30° W. and dips 65° W. The rocks are cut by other fissures, some striking about north-south, others about N. 65° W. No production has been reported from this property.

The June Bug lies farther east, on the same part of the shore. The country rock is green and purple siliceous shale and sandstone of the Ravalli group. The vein, which consists mainly of white quartz,

runs N. 75° W. and dips 80° S. It shows considerable specular hematite, a little bornite, and some chalcopyrite. Not enough development work has been done to disclose any mineralization of commercial importance.

The Pend Oreille copper properties are located near the Northern Pacific Railway, a few miles east of Hope. The country rock is a bluish-gray shale belonging to the Newland formation. The main lead is about 11 feet wide, and its walls are fairly well defined. It seems to trend about N. 55° W. and to dip 80° NE. The croppings show cupriferous pyrite, but the vein has not been sufficiently opened to reveal its extent and value.

TROY DISTRICT.

Troy is a small town on the Great Northern Railway near the western boundary of Montana. It is the natural distributing point for the mining properties on Callahan Creek and Grouse Mountain, which hold out considerable promise of becoming active producers.

MINES ON CALLAHAN CREEK.

On Callahan Creek, about 8 miles from Troy, are two lead-zinc mines, which are among the most promising in the region with which this paper deals. Some 8 miles farther up the creek there is a prospect in an ore body which is said to be a contact deposit. This prospect was not visited, but a few hours were devoted to an examination of the other properties, which are known as the Big Eight and the B. & B. mines.

In their general features these two mines are very similar. The ore bodies are in a fissure cutting argillitic and quartzitic sediments of the Prichard and Burke formations. The sediments strike about north-northeast and dip eastward. The veins strike about N. 30° W. and dip steeply westward; their strike is about parallel to that of the great Lenia fault, described on page 53, which lies not far to the east, and brings the red and green siliceous shales of the Striped Peak formation against the much older rocks in which the mines are situated. In both the mines an altered basic dike accompanies the vein, occupying, at least in part, the same fissure with the ore body. The ores are galena and sphalerite, in a gangue of very remarkable composition, which consists chiefly of silicates such as are generally formed by contact metamorphism.

The Big Eight mine is located on a narrow promontory between two forks of the stream and near their junction. The workings in 1905 consisted of an adit, a drift which is continued north of the northern branch of the stream, and a shaft of slight depth near the junction of the adit and the drift. The principal vein, well exposed

on the abrupt rocky banks of the stream, strikes N. 30° W. and dips 80° W. It is about 8 feet wide, and here has well-defined walls. A dike of a rather fine-grained dark-gray rock, which proves on microscopic examination to be much decomposed, but which is probably of diabasic or dioritic character, cuts the sediments here a few feet east of the vein. The ore is rather irregularly distributed, in places forming most of the vein, but being locally mixed with a large proportion of the silicate gangue and with fragments of country rock. It consists chiefly of sphalerite, which forms some large masses of great purity; it also comprises a variable, but, on the whole, subordinate amount of galena. A little pyrite occurs locally.

About 200 feet east of the principal vein the adit crosses a smaller one, which consists of nearly pure galena. Its strike is N. 30° W.; its dip, 65° W. Its width at the lowest point exposed is about 20 inches, but it narrows upward and pinches out near the roof of the tunnel.

The B. & B. mine is located on the rather steep slope south of the creek. The development work done there is more extensive than in the Big Eight mine, and the vein has been tapped by means of several tunnels. This mine was examined very hastily. The country rock is a gray-blue banded argillite, very similar to the typical Prichard slate of the Cœur d'Alene district. A dike rock similar to that in the Big Eight occurs here also, but its relation to the vein was not observed. The course of the vein is about the same as in the Big Eight. The ore is of the same peculiar character as in the other mine, but seems to contain a relatively larger amount of galena as compared with sphalerite.

Although both these mines had previously made considerable shipments of ore, neither was shipping at the time they were visited. The idleness of the B. & B. was said to be due to litigation. The Big Eight was being worked under a lease by Batchelder Brothers, of Spokane, and had about 150 tons of high-grade ore on the dump.

The remarkable mineral composition of the ore bodies exposed in these two mines makes the question of their genesis a problem of peculiar interest. The detailed description of the material has been deferred, therefore, to this point in order that it might be given in connection with the discussion of this problem.

The sphalerite and galena of the principal veins are associated with actinolite, chlorite, biotite, garnet, and magnetite, whose relative amounts vary widely in different specimens. Perhaps the most abundant constituent of the gangue is a dark-green, finely divided chlorite. This forms a sort of groundmass in which the other minerals are embedded. The amphibole, which appears in the hand specimen to be grayish green in color, but is nearly colorless in thin section, occurs in splintery crystals, which locally make up the greater

part of the gangue and show a tendency to form radiate groups. Garnet, of a brownish-red color, forms crystals which are penetrated by splinters of the amphibole. Greenish-brown biotite, forming small tablets embedded in the chloritic base—which, however, does not appear to have been derived from it—is locally abundant. Calcite, evidently not derived from the decomposition of the silicates, but essentially contemporaneous with them, is moderately abundant in some specimens.

Some thin sections show galena and amphibole intimately associated and apparently almost contemporaneous, for while the larger areas of galena are crossed by needles of actinolite showing automorphic development of the prism faces, the sulphide locally forms irregular veinlike masses within the amphibole. It is possible, however, that these are secondary, and the first-named relation appears the more significant one.

This combination of minerals would not be remarkable under certain geologic conditions. It is in a general way similar to that existing in many deposits which occur at the contact of calcareous sediments with intrusive igneous rocks. It is plain, however, that this deposit is not the result of the thermal action of the basic dike associated with it upon the noncalcareous sedimentary rocks into which this dike is intruded. In other parts of the region basic intrusions of similar petrographic character have been observed in contact with sedimentary rocks like those at this locality, but even where the mass of the intrusive rock is much greater its metamorphic effect has been small, amounting merely to a moderate degree of recrystallization. Furthermore, it involves no notable change in chemical composition; but the gangue of the Callahan Creek deposits is rich in magnesia, which is virtually absent from the adjacent sediments. Evidently, therefore, it consists of material brought from a distance.

That the deposit is in the nature of an emanation occluded from the dike itself is improbable because such deposits have not been observed in genetic relation with similar dikes, either in this region or, so far as I am aware, in others.

Another possibility worth consideration is that a metalliferous vein with a gangue composed largely of quartz and of carbonates of lime and magnesia may have been formed, and subsequently metamorphosed upon the reopening of the fissure and the injection of the dike. Unfortunately, no definite evidence regarding the relative age of the vein and the dike was observed in the field, but certain considerations tend to indicate that the dike is the older. In the first place, it does not seem likely that the intrusion of a rather small basic dike was adequate to produce the intense effect implied in the character of the coarsely crystalline aggregate of silicates that is found in the vein. In the second place, the highly altered condition of the dike rock

suggests that it has been subjected to the action of hot circulating waters, which may well have been the same that deposited the vein matter from solution. A third fact of similar tendency though of less weight is that at the Grouse Mountain prospects, presently to be described, the vein lies within, and is clearly older than, a basic dike similar in trend and character to that on Callahan Creek. There, however, the vein material differs from that of the Callahan Creek mines.

All the hypotheses thus far suggested being open to serious objection, we are forced to seek some other; and the character of the deposit is such that it must have been formed essentially by igneous agencies. The large body of granitic rock occurring farther up the stream, as attested by hearsay evidence and by the presence of abundant granite bowlders in the stream bed, may be considered, in accordance with the modern theories of ore deposition, as a likely source of the minerals in this vein. It is readily conceivable that the batholithic mass extends beneath the mines, and that the ores were deposited in a fault fissure by emanations from the granitic magma.

GROUSE MOUNTAIN PROPERTIES.

Grouse Mountain is a spur of the Cabinet Range, lying between the headwaters of Callahan and Lake creeks.

The Great Northwestern property is situated on the southwestern slope of the mountain. The country rock is grayish siliceous shale, probably of the Prichard formation, which is cut by a large diabase dike trending northwest and southeast. A fracture zone parallel to and lying within this dike forms the vein. It is filled with white quartz, calcite, and iron-stained breccia, is from 2 to 6 feet wide, and carries galena, some iron pyrite, marcasite, siderite, sphalerite, and a little chalcopyrite. The ore is said to carry from 18 to 50 ounces of silver per ton, and seems to occur in irregular bunches. The vein appears to be richer where it is cut by a porphyry dike of later origin. About 60 tons of ore are on the dump, awaiting the construction of a wagon road to Troy, 12 miles distant.

The Iron Cap claim adjoins the Great Northern, and seems to be on the same fissure, which here cuts typical Prichard slate. It has been opened up by a shallow open cut, exposing a large amount of iron capping and crushed vein material. Some pieces of galena are found in the less weathered parts.

SYLVANITE.

Location.—Sylvanite is situated in the Purcell Mountains, on Yaak River, about 12 miles from its mouth. It may be reached by a wagon road from either Troy or Bonners Ferry, between which points there is no means of taking horses across Kootenai River.

Mines.—The principal mining properties near Sylvanite are the Keystone and Goldflint, which are located on the same lode. Their country rock is gray sandstone with some shaly beds, and represents typically the quartzite phase of the Prichard as developed in the northwestern part of the region. The general strike is about north-south, and the dips are eastward at low or moderate angles. The sediments are cut by basic dikes of dioritic aspect.

The vein, which is generally about 1 or 2 feet in thickness, appears to be nearly parallel to the bedding planes, and its dip is variable, averaging about 40° E. The ore consists of deeply weathered auriferous pyrite in a gangue of quartz, which includes many iron-stained fragments of the crushed country rock.

The extent of the workings would indicate that the mine had produced considerable free-milling gold ore. This ore was concentrated in a 10-stamp mill. The properties were idle at the time of our visit, owing, it was reported, to litigation. It is possible that base ore which could not be treated by the free-milling process had been found in depth. No production has been reported since our visit.

SNOWSHOE MINE.

General statement.—The Snowshoe mine, owned by the Rustler Mining and Milling Company of Pittsburg, comprises three patented claims, the Snowshoe, Rustler, and Porcupine. Information regarding the output, values, etc., of the mine was courteously afforded by the manager.

Location.—The Snowshoe mine is situated in the most rugged part of the Cabinet Range. It is on a branch of Libby Creek and just across the divide from Bull Lake.

A good wagon road down Libby Creek connects the mine with the Northern Pacific Railway at Libby, about 22 miles to the north. Several four and six horse teams haul out ore and bring in supplies over this road.

Character of vein.—The Snowshoe vein occupies the fissure of the Snowshoe fault, described on page 54. The country rock on the east side of the fault consists of grayish-green to dark-gray indurated arenaceous shales and flaggy sandstones of the Burke formation; that on the west side is a calcareous shale resembling that of the Newland formation, but probably younger. This shows that a throw of several thousand feet has occurred, but owing perhaps to the fact that the fissure is here almost perpendicular, there has been a minimum of friction and the movement has not caused extensive crushing of the wall rocks. This principal vein trends almost exactly north-south.

One section of the vein as exposed in the mine shows a thickness of 5 feet. Next to one of the walls is about 2 feet of dark gouge

mingled with slickensided fragments of wall rock; the remaining 3 feet consists chiefly of quartz mingled with a little siderite and inclosing irregular masses of galena. Near the other wall, which has little gouge, this material is banded and sheared. Another section, on the third level, shows about 6 feet of good ore. The gangue is chiefly quartz, with which siderite, pyrite, and galena are somewhat intimately mingled. The galena forms some streaks as much as 6 inches wide, and is slightly more abundant near the western wall than elsewhere. At this place the dip of the vein is a little toward the west; the walls are well defined, and there is but a few inches of gouge on either side.

Another smaller vein lies about 75 feet east of the main fissure and almost parallel to it. The filling material is principally white quartz and crushed rock, with a few inches of shiny black gouge on the east and a little greenish-blue gouge on the west wall.

Development work has opened up 300 or 400 feet of depth on the vein, showing lenticular masses of galena and an average width of about 7 feet.

Ores.—The values in the ore are derived chiefly from argentiferous galena, but it carries a gold value of about $1.50 per ton, which is said to increase with depth. An average assay shows about 10 per cent of lead and 5 ounces of silver per ton. This ore, concentrated, approximately, 6 to 7 into 1, yields about 50 per cent of lead, 25 ounces of silver, and $5 to $10 in gold. In view of the long wagon haul, it is very desirable that the concentration be carried as far as possible. This results in the loss of a large proportion of the gold values, probably as high as $400 a day. The mine was said, at the time of our visit, to have shipped in all about $850,000 worth of ore, mainly to the smelter at Everett, Wash.

Plant.—The concentrating plant is driven by water power, except the compressor and electric-light plant, which during the dry season are driven by steam.

The water power is now obtained by damming water in glacial cirques above the mine. This storage could be greatly increased and a considerable saving on steam be thus effected by improving the position and increasing the size of the dams.

Future prospects.—This property at the time of our visit was the leading producer in the region north of the Cœur d'Alene district, and gave strong indications that before long the output would be considerably increased. It reported no production, however, in 1906, and is said to have been involved in litigation. The great lode on which it is located is traceable for some miles, and is being explored in several of the numerous claims staked along its course. Handsome specimens of coarsely crystalline galena were shown us, which were said to come from the Alpine prospect on Leigh Creek,

south of the Snowshoe mine, but probably on the same lode. If the present development continues, a branch from the main line of the Great Northern Railway may soon be warranted. Such a branch line could be built easily and cheaply up the gentle grade of Libby Creek. It would pass through excellent timber land and would greatly encourage mining in the district.

CABINET DISTRICT.

Location.—The name Cabinet district is here applied to an area lying in the Cabinet Mountains, about 20 miles southeast of the Snowshoe mine. It comprises the properties on Silver Butte Mountain and those on the headwaters of Fisher River. The former are reached from Trout Creek, on the Northern Pacific Railway, by a wagon road, about 15 miles long, up Vermilion Creek. Entrance into the Fisher River country is made by wagon road from Libby, 25 miles to the northwest, its nearest railway point.

Silver Butte mine.—The Silver Butte property is located on a vein which strikes N. 60° W. and dips 30° S., and cuts across Silver Butte. The country rock is the blue Prichard slate, associated with some beds of grayish arenaceous shale. The vein averages 10 feet in width, but an outcrop on top of the mountain shows white quartz to the width of 30 feet, which can be traced for about half a mile. The ore is composed of galena, which is scattered through lenses of white quartz. Some sections of the vein show only barren white quartz, crushed country rock, and gouge.

In a concentrating plant erected at a reported cost of $150,000 some ore has been milled. Some years previous to 1905, while temporarily closed down, this plant was burned to the ground, and the mine had since been idle.

The exploration work has exposed values enough to indicate that systematic development might open up sufficient low-grade silver-lead ore to make the property a regular producer. Several other locations are on what appears to be the same vein, but as yet little work has been done on them.

Mines at head of Fisher River.—Just across the divide of the Cabinet Range, in the Fisher River drainage, about north of Silver Butte, is a group of properties upon which a large amount of work has been done. They were once sufficiently productive to lead to the construction of three stamp mills, but they are now almost completely abandoned. None of them were entered in the course of this reconnaissance, but their general character was evident from the outcrops of the veins and the distribution and form of the workings. The lodes are situated near the crest of the Cabinet anticline, and are blanket veins parallel to the stratification, which dips at low angles. The country rock is typical Prichard slate. The vein material is

chiefly quartz, with pyrite and gold, forming a rather low-grade ore which has apparently failed to yield profits below the zone of oxidation.

PROSPECT CREEK DISTRICT.

Location.—Prospect Creek heads in the Cœur d'Alene Mountains, near Thompson Pass. It flows into Clark Fork, near Thompson Falls, and is just across the divide to the northeast of the Coeur d'Alene mining district. A wagon road, which connects Thompson Falls with Murray and Wallace in the Cœur d'Alene district, follows the valley of Prospect Creek, and furnishes convenient access to the properties located in its drainage basin.

Mines and properties.—The Rosebud Mining Company is exploring several claims near the mouth of Rosebud Creek, a small tributary which enters Prospect Creek about 9 miles above its mouth. A vein of white quartz has been found by this company in the upper part of the Prichard formation. One of the owners reports that it carries some silver chloride and over $100 per ton in gold in the weathered zone at the surface.

The Montana Standard group of four claims is on Prospect Creek about 11 miles above its mouth. The vein is associated with a massive basic dike which cuts a country rock of the Burke formation. An adit driven on the east contact of this dike shows irregular masses of white quartz carrying galena. About 400 feet from the mouth of this tunnel a fairly well-defined cross lead runs N. 20° E. and dips 70° E. It shows some evidence of shearing and carries galena and siderite. On the west side of the dike a flat vein outcrops. It is 3 to 4 feet thick, strikes about N. 15° E., and dips 15° W. No connection between this vein and the ore deposit on the east side of the dike was apparent. The ore seems to lie in irregular bunches and cross fissures along the east contact of the dike. The examination of this property was very hurried, but it would seem advisable in the course of the present active development work to explore the east contact of the dike.

A few miles farther up Prospect Creek is an antimony vein from which a considerable amount of ore is said to have been shipped some years ago. This vein is not now being worked. Other claims in addition to those mentioned have been located on this creek, but they have been very little developed.

MISSOULA VALLEY.

General statement.—The valley of Missoula River below Missoula has been the scene of considerable mining development, but here, as in many other parts of the region, the industry is less active now than formerly. Large amounts of gold have been taken from placers on

the streams which enter the valley from the south. Copper deposits are being developed in the mountains south of the river, but their future value can not as yet be predicted with confidence. The values shown in prospects north of the river are chiefly in galena, but few of the veins in this area have been developed to the point of actual production. The only property in the Missoula Valley region that was visited was the Iron Mountain mine, situated about 5 miles north of Iron Mountain station on the Northern Pacific Railway.

Iron Mountain mine.—This property, once the most important in the district, is now idle. It began to produce about fourteen years ago and was worked for eight years, during which period it yielded about half a million dollars in dividends besides paying the expenses of mine development, the building of a 200-ton mill, and the construction of 15 miles of mountain road. This road, which was used before the Cœur d'Alene branch of the Northern Pacific Railway was constructed, crosses the divide north of the mine and leads down to a point on Missoula River a few miles from its mouth, whence the ore was floated down on barges to the main line of the Northern Pacific. The closing of the mine was due to the enactment of a state law which requires that every mine shall have two openings. It has now been determined to comply with this law by the construction on the 1,500-foot level of a tunnel which will be over a mile in length. The surveys for the tunnel have been completed and its construction has been begun, so that in the near future the mine will probably resume its place as a producer.[a]

The country rock is a somewhat calcareous, light-green argillite of the Newland formation. The ore body is in a fissure vein about 5 feet in average width, striking nearly northwest-southeast and dipping steeply to the northeast. The ore, which occurs in a quartz gangue mingled with fragments of country rock, is argentiferous galena with a little sphalerite, carrying about 6 ounces of silver to the ton. The concentrates form about 45 per cent of the ore as mined.

MINING PROPERTIES NOT VISITED.

The region contains a large number of prospects concerning which we obtained no information at either first or second hand. A few of the properties that we did not visit seem to deserve mention.

The Buckhorn mines, situated in the rugged mountains east of Mooyie River and about 10 miles north of Kootenai River, have produced some good-looking ore containing both gold and galena. So far as development had gone at the time of our visit, the ore was said to be free milling. The development work reported in 1906 consisted of the driving of 2,000 feet of tunnel and the erection of a 5-stamp

[a] The completion of this tunnel has since been reported.

mill. It has been connected by wagon road with the main highway along Kootenai River.

About the headwaters of the tributaries which enter Bull River from the west there are a number of copper prospects, but, so far as could be learned, they have not been very extensively developed.

At Libby we were shown some fairly good samples of galena, said to have been taken from a contact deposit on Rainy Creek, which enters Kootenai River on the north, about 6 miles upstream from Libby.

OUTLOOK FOR THE REGION.

In regard to the region as a whole, the similarity of its rocks to those of the Cœur d'Alene district, together with its position between that district and the great producing mines of southern British Columbia, mark it as a promising field for the prospector. Moreover, large faults and their accompanying smaller fractures afford channels of circulation for underground waters and fulfill one of the conditions for the deposition of ore. Intrusive igneous rocks, which in other mining regions have also been recognized as favorable to mineralization, are developed in considerable abundance.

In general, the reconnaissance has left a strong impression that systematic and wisely directed development might considerably increase the mineral production of northern Idaho and adjacent portions of Montana.

INDEX.

A.

Page.

Acidic intrusives, character and distribution of ... 43–47
Acknowledgments to those aiding ... 9
Agriculture, progress of ... 21
Algonkian rocks, character and distribution of ... 27, 35–42, 50–51
  correlation of ... 39–42
  intrusion in ... 28
Alpine prospect, ore from ... 104–105
Anderson group, description of ... 94
Antimony, occurrence of ... 106
Archean rocks, character of ... 33–34
  distribution of ... 27, 33, 34

B.

B. & B. mine, description of ... 99–102
Basalt, character of ... 51
  distribution of ... 29, 51, 59
Basic intrusives, character and distribution of. 47–50
Bear Peak, elevation of ... 15
  rocks at and near ... 39, 79–81.
  section on ... 80
Belt Mountains, rocks in ... 40
Belt series, character and distribution of ... 9, 28, 33–34, 35
Bernard Peak, rocks of ... 45, 59
Big Eight mine, description of ... 99–102
Blackbird mine, production of ... 98
Blackfoot limestone, correlation of ... 38, 40
Blacktail Mountain, rocks near ... 61
Blacktail Point, mines at ... 97–98
  rocks of ... 60
Blue Creek, rocks on ... 64
Bonners Ferry, description of ... 25
  rocks near ... 36, 44, 48, 56, 70
Boyer, rocks near ... 44
Browne mine, description of ... 97–98
Buckhorn mines, description of ... 107–108
Bull Lake, drainage of ... 15
  landslide near ... 65–66
    figure showing ... 66
  location of ... 15
  rocks near ... 45, 46, 65–68, 80
Bull Lake fault, description of ... 52, 55, 66–68
  section of, figure showing ... 67
Bull Lake valley, character of ... 15
  rocks of ... 65–68
Bull River, basin of, mines in ... 108
  mouth of, glaciation at ... 31
  rocks on ... 65–66
Burke, rocks near ... 87
Burke formation, character and distribution of ... 37, 58, 61–62, 73, 78, 79, 81–82, 84, 85, 86, 91, 99, 106

C.

Page.

Cabinet district, mines of ... 105–106
Cabinet Range, description of ... 14–16
  fold in ... 56
  roads in ... 23, 24
  rocks of ... 36, 37, 38, 39, 41, 45, 46, 48, 55, 64, 77–83
Callahan Creek, mines near ... 99–102
  rocks on and near ... 36, 46, 54, 69, 71
Camp Creek series, correlation of ... 38, 39, 40, 90
Canfield Butte, rocks near ... 59
Cape Horn, rocks near ... 45, 60, 62
Chamberlin, T. C., on Cordilleran ice sheet ... 31
Cherry Creek, rocks near ... 77–78
Chilco Mountain, rocks near ... 44, 59
Chloride, boom at ... 95
Clarkfork, rocks near ... 63
Clark Fork valley, description of ... 18
  fault in ... 63
  glaciation on ... 31
  rocks in ... 29, 31, 63–65, 81, 83–88
Climate, description of ... 20
Cœur d'Alene, description of ... 26
  rocks near ... 34
Cœur d'Alene district, faulting in ... 52
  rocks of ... 7, 36, 41, 73
  trails to ... 24–25
Cœur d'Alene Lake, description of ... 19–20
  location of ... 17
  origin of ... 29, 32
  rocks near ... 29, 33, 34, 51, 59–60
Cœur d'Alene Range, description of ... 13–14
  drainage of ... 14
  roads in ... 23, 24–25
Cœur d'Alene Valley, description of ... 18–19
  rocks in ... 29, 51, 58–59
Columbia Plain, location and character of ... 10
  rocks of ... 29
Conjecture mine, description of ... 96
Copper, occurrence of ... 93, 99, 107
Correlation of Algonkian rocks ... 39–42
  table showing ... 40–41
Creston quartzite, character and distribution of ... 63, 71

D.

Daly, R. A., on correlation ... 41–42
  on geology of region ... 34, 49
  on glaciation in region ... 31
  on mountain subdivisions ... 11–13
  on subequality of ridges ... 30
Deep Creek, rocks on ... 83–84
Dikes, character and distribution of ... 47
Diorite, character and distribution of ... 48–50
Dixon, rocks near ... 36, 88
Douglas mine, description of ... 94–95

E. Page.

Economic geology, description of..... 92-108
Eddy, rocks near..... 86,87,90
Eightmile Prairie, description of..... 17
Ewing, Mount, rocks near..... 72

F.

Faulting, occurrence and character of..... 52-56
Field work, extent of..... 7-8
Fires, destruction by..... 20-21
Fisher River, fold on..... 56-57
mines on..... 105-106
rocks on..... 81-82
Fissure veins, character of..... 92-93
Flathead quartzite, occurrence and character of..... 88-89
Flathead Valley, description of..... 18
rocks in..... 29,50,83-88
Folds, description of..... 56-57
Forest, character of..... 20-21
Forty-ninth parallel, rocks near..... 41-42
travel along..... 23
Fossils, occurrence of..... 28,35,39,43,83

G.

Galena, occurrence of..... 93,107,108
Geographic Board, United States, on Rocky Mountain system..... 12
on Clark Fork of Columbia River..... 18
Geography, description of..... 10-26
Geologic map of district..... 26
Geology, outline of..... 27-33
summary of..... 27-57
Geology, areal, description of..... 58-91
map showing..... 26
Geology, economic, description of..... 92-108
Girty, G. H., fossils determined by..... 43
Glaciation, extent and effects of..... 31-32
Glaciers, existence of, in Cabinet Range..... 15,20
Gold, occurrence of..... 93,106
Goldflint mine, description of..... 103
Goode, R. U., on trails..... 24
Granite Creek, rocks on..... 47
Granodiorite, character and distribution of.. 45-46
Great Northern Mountain, elevation of..... 15
Great Northwestern mine, description of..... 102
Green Monarch mine, description of..... 98
Grouse Mountain, mines on..... 102
rock of..... 69

H.

Hawkins Creek, rocks near..... 71-72
Hayden Lake, rocks near..... 43,59
Heron, fault near..... 65
rocks near..... 37,63,64
Hidden Treasure mine, description of..... 96
Hope, description of..... 26
rocks near..... 46,47,48,61,63,64,69
Hope fault, description of..... 52,53,55
Horse Plains, character of..... 18

I.

Igneous rocks, character and distribution of. 43-51
intrusion of..... 28
relation of, to metal deposits..... 93
Industries, character of..... 21

Page.

International boundary. *See* Forty-ninth parallel.
Intrusive rocks, character and distribution of. 43-50
Iron Cap claim, description of..... 102
Iron Mountain, rocks near..... 89-91
Iron Mountain mine, description of..... 107

J.

Jennings, rocks near..... 77
June Bug mine, description of..... 98-99

K.

Keeler Creek, rocks near..... 67
Keep Cool group, description of..... 96
Keystone mine, description of..... 103
King mine, description of..... 94
Kitchener quartzite, correlation of..... 37,39,41,71
Kootenai Falls, rocks near..... 75
Kootenai River, drainage of..... 17
faults and folds on..... 54,57
rocks near..... 36,39,41,50
valley of, description of..... 17-18
rocks in..... 68-70,75-77
section in..... 76

L.

Laclede, rocks near..... 34,44
Lake Creek, rocks near..... 75
Lakes, location and character of..... 19-20
Lakeview, rocks near..... 42,60,62
boom at..... 95
ore from..... 96
Lamprophyre, character and distribution of. 47
Leiberg trail, description of..... 24
Leigh Creek, rocks near..... 79,104-105
Lenia, rocks near..... 36,48
Lenia fault, description of..... 52,53-54,68-69
Lewis Range, rocks of..... 40
Libby, description of..... 25
mines near..... 108
rocks near..... 75-79
Libby Creek, rocks near..... 77
Lightning Creek, rocks on..... 45,46,63
Lime, manufacture of..... 94,97
Limestones, age of..... 28,43
character and distribution of..... 28,38,43, 60,62,68,76,97
Lindgren, Waldemar, on Cœur d'Alene Range..... 13-14
on subequality of ridges..... 30
Little North Fork, rocks on..... 44,60
Livingston Range, rocks of..... 40
Location of region, description of..... 7-8,10
map showing..... 8
Lothrop, fossils near..... 28
rocks near..... 43,88-90
Lumbering, progress of..... 21

M.

MacDonald, D. F., on economic geology of the region..... 92-108
work of..... 9,48,63,74,77,83,92
Mameloose Island, rocks of..... 61
Map, geologic, of region..... 26
Map, index, of region..... 8
Metalliferous deposits, nature of..... 92-93

Page.
Military gulch, rocks near 87
Mining, outlook for 21, 108
progress of 21
Miocene rocks, character and distribution of. 51
Mission Range, location and character of 12
rocks of 38, 40, 89
Missoula, fossils near 30
rocks near 29
Missoula River, trails on 25
valley of, description of 19
mines in 106–107
rocks in 43, 50, 88–91
Montana Standard group, description of 106
Mooyie argillite, correlation of 38, 41
Mooyie River, location of 16
fires on 21
rocks on 36, 48, 50, 71
valley of, roads in 22–23
Mountain zone, description of 10
Mountains, divisions of 10–11

N.

Nabob mine, description of 95
Naples, rocks near 44
Nevada Stuart mine, description of 95
Newland formation, character and distribution of 38, 59–65, 68–70, 73–75, 81, 83, 85, 86, 87, 90, 95–99, 107
correlation of 38, 40, 72, 74

O.

Osburn fault, description of 58

P.

Pack River, course of 17
Packsaddle Mountain, rocks of 45
Paradise Spring, description of 88
rocks near 36, 88, 91
Pend Oreille copper prospect, description of. 99
Pend Oreille Lake, description of 19–20
glaciation near 31
lime plant near 94–97
mines near 95–99
moraine dam of 32
rocks near 36, 42, 45–46, 47, 48, 59–63
views on 62
Philipsburg quadrangle, rocks in 30, 40
Physiography, description of 10–13
Pine Creek, mines near 94–95
Plains, description of 26
rocks near 29, 36, 48, 50, 85–88
Porcupine mine, description of 103–105
Porthill, rocks near 56
Post Falls, rocks at 33
Prichard formation, character and distribution of 35–37, 58–60, 62, 69–72, 74, 78, 81–83, 85, 88, 91, 94, 99–102, 105
correlation of 36, 37, 40
gold in 93
Prospect Creek, mines on 106
rocks on 85
Purcell Range, description of 16
drainage of 16
rocks of 71–75

Page.
Purcell trench, description of 16–17
faulting in 35, 55
location and character of 11
roads in 22–23
rocks in 41

Q.

Quartz, rocks near 90–91
Quartz monzonite, character and distribution of 43–46

R.

Railways, routes of 22
Rainy Creek, mine on 108
Ransome, F. L., aid rendered by 9
on age of crystallines west of Purcell trench 35
on faulting in Purcell trench 56
on ore deposits 93
work in charge of 7
Rathdrum Valley, description of 17
Ravalli group, character and distribution of. 36, 37–38, 60, 64, 70, 71, 74, 85, 98
correlation of 37, 40
galena in 93
Revett formation, character and distribution of 37, 64, 70, 71, 84, 87
Rocky Mountain system, description of 12
Rocky Mountain trench, location and character of 11
southward extension of 12
Rosebud Mining Co., claims of 106
Rustler Mining & Milling Co., property of ... 103

S.

St. Maries River, rocks on 51
St. Regis formation, character and distribution of 37, 60, 62–63, 65, 73–75, 84–87, 90, 91
St. Regis River, course of 19
Sandpoint, description of 25–26
rocks near 35, 44, 46, 48
Scotchman Peak, rocks near 36, 55, 64, 71
scenery near 15
Selkirk system, description of 12–13
Settlements, location and character of 25–26
Sills, character and distribution of 48
Silver, occurrence of 93, 96
Silver Butte, mines on 105
rocks of 81–82
Silver Butte mine, description of 105
Snowshoe, rocks near 78
Snowshoe Creek, rocks on 79
Snowshoe fault, description of. 53, 54–55, 78, 79, 80, 84
Snowshoe mine, description of 103–105
Spokane, fossils near 35
rocks near 29
Spokane Junction, rocks near 36, 71
Spokane River, rocks near 29, 33, 58–59
Squaw Bay, lime plant at 94, 97
rocks at 42, 62
Station Creek, rocks on 68
Stone Creek, mines on 95
Stratigraphy, account of 33–51

Page.
Striped Peak formation, character and distribution of.. 38-39, 60, 63-64, 69-70, 72, 89
correlation of..... 38-39, 41, 74
Structure, description of..... 52-57
Surprise mine, description of..... 95
Swamp Creek, fossils on..... 28
glaciation on..... 31
rocks on..... 78, 82-83
Syenite, character and distribution of..... 46-47
Sylvanite, description of..... 25, 102
mines at..... 103
rocks near..... 36, 48, 70

T.

Thompson, rocks near..... 83-85
Thompson Falls, origin of..... 84-85
Thompson Falls (town), description of.... 26, 65
rocks near..... 84
valley at, character of..... 18
Thompson Pass, rocks near..... 87
Thompson River, rocks on..... 86
Thornton, rocks at..... 63
Threemile Point, rocks at..... 34
Topography, description of..... 13-20
Trails, description of..... 23
Travel, routes of..... 22-25

Page.
Troy, description of..... 25
mines near..... 99-102
rocks near..... 70, 71, 75

V.

Vegetation, description of..... 19-20
Vermilion Creek, rocks near 36, 46, 48, 65, 81-84
Volcanic rocks, character and distribution of. 50-51

W.

Wagon roads, routes of..... 22-23
Walcott, C. D., on geology of region..... 38, 40, 89
work of..... 8-9
Wallace formation, correlation of..... 38, 41
Webber group, description of..... 96
Weed, W. H., work of..... 7
Willis, Bailey, on geology of region..... 40
work of..... 7

Y.

Yaak River, drainage of..... 16
forest on..... 21
rocks near..... 36, 48, 50, 70-75
trails along..... 23-24

Z.

Zinc, occurrence of..... 93

O

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 385

BRIQUETTING TESTS

AT THE

UNITED STATES FUEL-TESTING PLANT NORFOLK, VIRGINIA, 1907-8

BY

CHARLES L. WRIGHT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

CONTENTS.

	Page.
Introduction	5
Previous work	5
Norfolk plant	5
Personnel	6
Definition of briquets	6
Briquetting tests	7
Purpose	7
Coals briquetted	7
Binders used	7
Character of tests	8
Combustion tests	8
Physical tests	8
Drop test	8
Tumbler test	9
Weathering test	9
Absorption test	9
Density test	10
Briquetting temperature	10
Briquetting equipment	10
General description	10
Briquetting machines	11
Nature and capacity	11
Detailed descriptions	12
English machine	12
American machine	14
Details of tests	16
Jamestown No. 2	16
Jamestown No. 3	17
Jamestown No. 5	19
Jamestown No. 6	20
Jamestown No. 7	21
Jamestown No. 8	22
Jamestown No. 9	25
Jamestown No. 10	26
Jamestown No. 11	27
Jamestown No. 12	29
Jamestown No. 13	30
Jamestown No. 14	31
Jamestown No. 15	33
Jamestown No. 16	34
Jamestown No. 17	36
Jamestown No. 18	36
Bibliography	36

ILLUSTRATIONS.

		Page
PLATE I.	Plan of briquet equipment at Norfolk fuel-testing plant	8
II.	Some American and foreign briquets	10
III.	General view of briquetting machines	10
IV.	Side view of English briquetting machine	12
V.	Elevation of English briquetting machine	12
VI.	*A*, Hopper and scales back of English machine; *B*, Stedman disintegrator	12
VII.	Elevation of American briquetting machine	14
VIII.	*A*, Pitch cracker and scales and hopper back of American machine; *B*, Arrangement and driving gear of pitch and coal mixing conveyors	14
IX.	*A*, Car-loading conveyor delivering briquets to car; *B*, Plant end of car-loading conveyor, showing cross conveyor	14

BRIQUETTING TESTS AT THE UNITED STATES FUEL-TESTING PLANT, NORFOLK, VIRGINIA, 1907-8.

By CHARLES L. WRIGHT.

INTRODUCTION.

Previous work.—The general plan of work outlined for the United States Geological Survey fuel-testing plant erected at the Louisiana Purchase Exposition, at St. Louis, Mo., in 1904, included investigations relative to the briquetting of coals found in the United States. These investigations embraced the possibility of making satisfactory commercial fuels from lignite or low-grade coals which do not stand shipment well; of benefiting culm or slack coals that are wasted or sold at unremunerative prices; and of improving the furnace efficiency or ability to withstand transportation of good coals. This work was begun in 1904 and was continued in 1905, 1906, and 1907 as an essential part of investigations looking to the determination of methods for reducing waste in coal and increasing efficiency in the utilization of the fuel resources in the United States.

The initial briquetting tests at St. Louis, which included examination into the behavior of different coals or mixtures of coals in the briquetting press, experimental study of the merits of various substances used as binders, and consideration of the physical properties and resistance to weather and abrasion of the briquets, have been described.[a] They demonstrated that satisfactory briquets could be made from most coals, and that by briquetting the commercial value of many low-grade coals and lignites could be raised enough to more than cover the cost of manufacture.

Norfolk plant.—The briquetting plant of the Geological Survey was moved from St. Louis, Mo., to Norfolk, Va., in 1907, along with the steam boiler and producer-gas equipment of the fuel-testing plant, as the closing out of the affairs of the Louisiana Purchase Exposition and the consequent removal of the buildings from Forest Park made a change of location necessary. Norfolk was selected largely with a view to the testing of coals for naval purposes, and because of facilities in the way of buildings and materials offered

[a] See Professional Paper 48, pt. 3; and Bulletins 261, 290, 332, and 343.

by the Jamestown Exposition Company. The work at Norfolk was chiefly devoted to making steaming and briquet tests of coals which reach the Atlantic seaboard at Norfolk and Newport News and are used by the navy and merchant marine.

Two briquet machines were installed at the Norfolk plant, one being the English machine used in briquetting tests by the Geological Survey at St. Louis in 1905 and 1906, and the other an American machine. The briquets made at this plant were tested on locomotives of several railroads entering Norfolk and on the United States torpedo boat *Biddle* in comparison with the run-of-mine coal used in making them. Some of the tests were conducted by the railroads on their own locomotives, but those on the *Biddle* and on the locomotive of the Seaboard Air Line Railway were carried on by W. T. Ray and Henry Kreisinger, of the Geological Survey.

Personnel.—Charles T. Malcolmson continued in general charge of the briquetting section after the removal to Norfolk until January 1, 1908. Walter J. Chapman continued in charge of operation of the briquet machines and of the observations reported under the heading "Details of manufacture." Charles L. Wright supervised the installation o the English briquet machine and later in the year continued the physical tests of briquets and the analyses in the chemical laboratory of the section until January 1, 1908, on which date he was placed in general charge of the work of the section. G. E. Ryder and Ralph Galt also continued with the staff, but the former was obliged to resign soon after the plant was in operation on account of ill health; the latter continued with the section as computer until the close of work on December 1, 1908.

DEFINITION OF BRIQUETS.

Briquetted or "agglomerated" fuel is fuel made by pressing in molds a mixture of coal dust and small-sized pieces of coal or other fuel material and a binding substance which holds the particles together. The most common binder at present commercially available is a pitch made either from coal tar or water-gas tar, but other substances, such as starch, lime, sulphite liquor, etc., have been used with more or less success. The mixture of coal and binder is heated and subjected to heavy pressure in molds.

Briquetted fuel has been manufactured in foreign countries for many years. Railroads and steamship companies operating in certain countries are required to keep a reserve supply of fuel on hand, and briquetted fuel has been found superior for this purpose to run-of-mine or slack coal, as it is free from danger of spontaneous combustion, which frequently occurs in large piles of fine coal. Briquetted fuel also resists the effect of weather better than slack or run-of-mine coal.

Foreign briquets vary in weight from a few ounces to 100 pounds, but the larger cakes are usually so marked off in pressing that they can be readily broken into small pieces suitable for use in stoves and steam boilers. The shapes and relative sizes of some foreign and American briquets are shown in Plate II.

BRIQUETTING TESTS.

PURPOSE.

The briquetting work undertaken at Norfolk had these specific objects:

1. To determine what per cent of pitch or other binder was necessary to make a satisfactory briquet out of the coals tested.
2. To investigate the relative merits of different binders.
3. To provide briquets for comparative combustion tests of run-of-mine coal and the same coal briquetted.

COALS BRIQUETTED.

During the period covered by this report, that is, from July, 1907, to January, 1908, 41 briquetting tests were made on the following coals:

Field designation.	Character and source of coal.	Briquets made.	Where tested.	Number of tests.
		Tons.		
J-2	Bituminous, r. o. m., Pocahontas, Va	161.85	Torpedo boat Biddle	4
J-3	Bituminous, r. o. m., Davy, W. Va	23.3	Testing station	3
J-5	Bituminous, r. o. m., Sewell, W. Va	69.0	Torpedo boat Biddle	2
J-6	Bituminous, r. o. m., Red Star, W. Va	20.7	do	1
J-7	Bituminous, r. o. m., Derryhale, W. Va	40.6	do	2
J-8	Bituminous, r. o. m., Lawton, W. Va	42.6	do	9
J-9	Bituminous, r. o. m., Winona, W. Va	25.0	do	3
J-10	Bituminous, r. o. m., Stanaford, W. Va	26.78	do	1
J-11	Bituminous, r. o. m., West Raleigh, W. Va	36.38	do	[a] 4
J-12	Bone coal, Switchback, W. Va	27.0		2
J-13	Bituminous, r. o. m., Ennis, W. Va	121.48	Seaboard Air Line Railway.	2
J-14	Semianthracite culm, Merrimac, Va	11.0	Kitchen stoves and grates.	1
J-15	Bituminous, r. o. m., Minden, W. Va	182.9	Chesapeake and Ohio Railway.	2
J-16	Bituminous, r. o. m., Midvale, W. Va	93.02	do	4
J-17	Bituminous, r. o. m., West Virginia	80.0	Battleship Connecticut	1
J-18	Anthracite, buckwheat size, Pennsylvania	3.0	Torpedo boat Biddle	[a] 1

[a] One test was made of 50 per cent of Jamestown No. 11 and 50 per cent of Jamestown No. 18.

BINDERS USED.

Two kinds of binders were used in these tests:

(*a*) Water-gas pitch.

(*b*) Flour.

Six different lots of water-gas pitch were used, the total weight consumed being 59 tons.

One lot of flour was tested as a binder.

The characteristics of the water-gas pitch binders used are found in the following table of results of tests and analyses:

Tests and analyses of water-gas pitch binders.

Chem. Lab. No.	Calorific value.	Flowing point.	Oils by distillation.				Pitch extracted by CS_2 from sample as received.
			Up to 572° F.	572° to 680° F.	680° to 743° F.	Total up to 743° F.	
	B. t. u.	*°F.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
4879[a]	16,805	126	1.33	16.53	15.15	33.01	94.50
5458	16,893	189	.88	12.34	22.44	35.66	92.92
5563	16,718	201	1.45	10.32	11.30	23.07	90.33
5939	16,781	194	1.87	4.21	14.54	20.62	98.13
5940	16,780	178	1.27	9.88	17.75	28.90	96.60
5941	16,978	196	1.71	14.05	16.20	31.96	98.44

[a] This binder was reported in Bull. No. 332, but it is included in this report also, as some of it was used in briquet tests herein described.

The flour binder used (laboratory No. 6110) had a calorific value of 6.998 British thermal units and the following proximate analysis:

Analysis of flour binder.

Moisture	13.30
Volatile combustible	72.30
Fixed carbon	13.50
Ash	.90
Sulphur	.10
Total	100.10

A few briquets were made from sulphite liquor, but as no record was kept of the details of manufacture and as not enough briquets were made for any of the physical tests, this binder can not be reported on until further experiments are made.

CHARACTER OF TESTS.

COMBUSTION TESTS.

Combustion tests of the briquets manufactured at the Norfolk plant were made in locomotive and marine boilers. A brief account of the tests appeared in Bulletin 363.[a]

PHYSICAL TESTS.

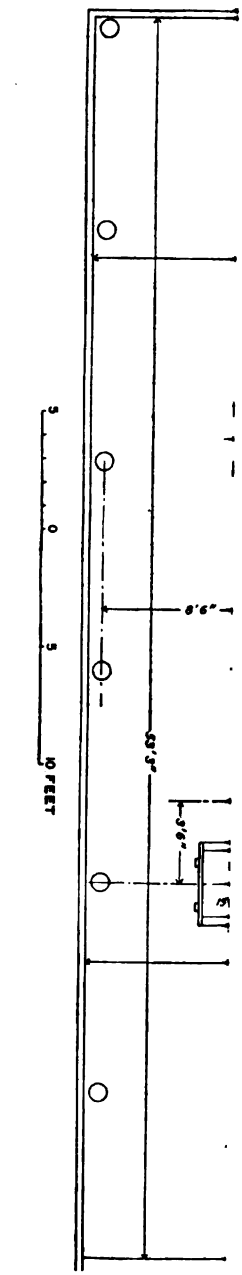
The methods of making the physical tests and of sampling the briquets can be found in Bulletin United States Geological Survey No. 332. Briefly these tests were as follows:

DROP TEST.

Fifty pounds of briquets were put in a box 24 inches square and 12 inches deep, with a drop bottom, 6½ feet above a cast-iron plate in

[a] Goss, W. F. M., Comparative tests of run-of-mine and briquetted coal: Bull. U. S. Geol. Survey No. 363. 1908, 57 pp.

U. S. GEOLOGICAL SURVEY



the bottom of a second box. The briquets were suddenly dropped on the plate, then screened on a 1-inch mesh wire screen. The pieces held on the screen were again dropped, the total number of droppings being five. At the last screening the percentage that the weight of the pieces held bore to the original weight of the briquets was called "per cent held by 1-inch screen," and the remainder was called "per cent through 1-inch screen."

TUMBLER TEST.

The briquets (as nearly as possible 50 pounds) were placed in a tumbler, a horizontal sheet-steel cylinder, and rotated two minutes at a uniform speed of 28 revolutions per minute, after which the contents of the tumbler were sized by a 1-inch mesh screen, and the portion passing through was screened through a 10-mesh sieve. The weight of the pieces held by each screen was determined and the percentage held computed.

WEATHERING TEST.

The conditions of briquets that had been placed in small piles in a yard and exposed to weather were noted. The time exposed and the condition of the briquets at the end of that time are stated in the tabulated results of tests. The key to the designated conditions A, B, C, D, and E is the same as stated in Bulletin 332:

A: Briquets practically in same condition as when put out. Surfaces show no signs of erosion or pitting. Briquets hard, with sharp edges, and fracture same as that of new briquets.

B: Shape of briquets unchanged. Surfaces of those on top of pile have lost luster, with evidences of pitting, corners and edges worn off by erosion. All briquets firm, with fracture practically the same as that of new briquets.

C: Top briquets appear similar to those in condition B, and show signs of further disintegration, having lost original sharp fracture. Erosion more evident on all briquets on outside of the pile. Inside briquets still firm, retaining original characteristics.

D: Top briquets so badly disintegrated that they crumble to pieces on handling. Briquets in center of pile show signs of disintegration; luster of surfaces gone; edges soft, and break easily in the hand. Fracture not so sharp as when newly made, but briquets firm, and handled without breaking.

E: Entire pile disintegrated. In many cases the only briquets retaining their original shape are those protected from the weather. Briquets can not be handled safely, but crush easily in the hand.

ABSORPTION TEST.

Samples of the briquets, one English briquet or four American briquets, were weighed in air and in water by a hydrostatic balance; the briquets were then kept covered in water and weighed in water daily

for varying periods up to several weeks. The results show the time immersed, the percentage of water absorbed, and the percentage absorbed in the first four days of the test.

DENSITY TEST.

This was determined from the first weighings for the absorption test.

BRIQUETTING TEMPERATURE.

The "briquetting temperature" reported in the tables of results (pp. 16 to 35) is the temperature of the mixture of fuel, binder, and moisture just before it was pressed into briquets.

The amount of moisture desirable in the briquet mixture before briquetting has been a disputed point among engineers. Consequently during this series of tests samples of the briquet mixtures were taken just before being briquetted, and were immediately sealed and forwarded to the chemical laboratory of the fuel-testing plant. The total moisture determined by analysis is reported in the tables as "moisture in briquet mixture."

BRIQUETTING EQUIPMENT.

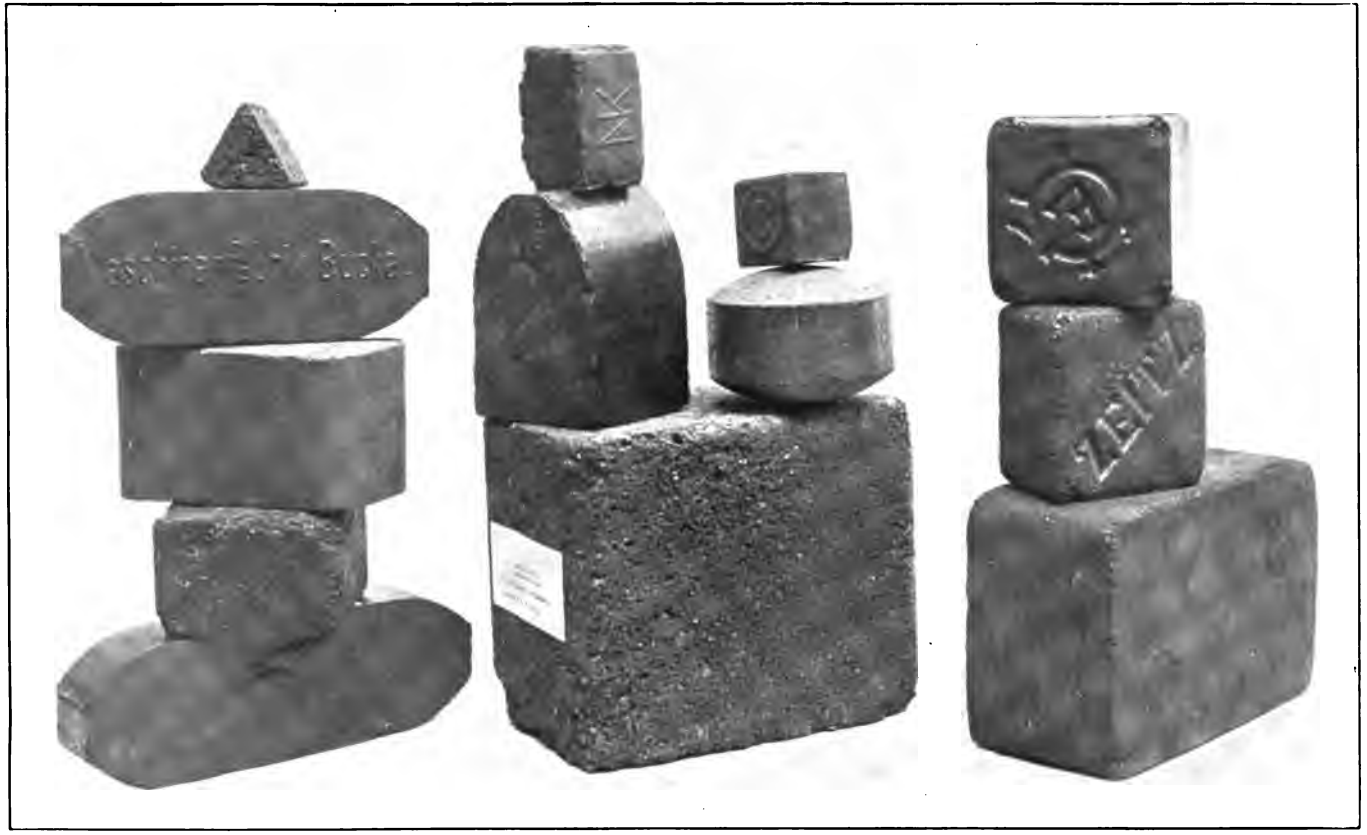
GENERAL DESCRIPTION.

The equipment of the United States Geological Survey briquet plant at Norfolk comprised two briquet machines (English and American), heating and mixing apparatus, storage bins for the raw fuel, crushers, grinder, and disintegrator for reducing the fuel to the desired fineness, machines for crushing or "cracking" pitch, scales, and the necessary elevators and conveyors. Most of the equipment had been used for varying periods of time at the St. Louis plant, but the American briquet machine had not been used before.

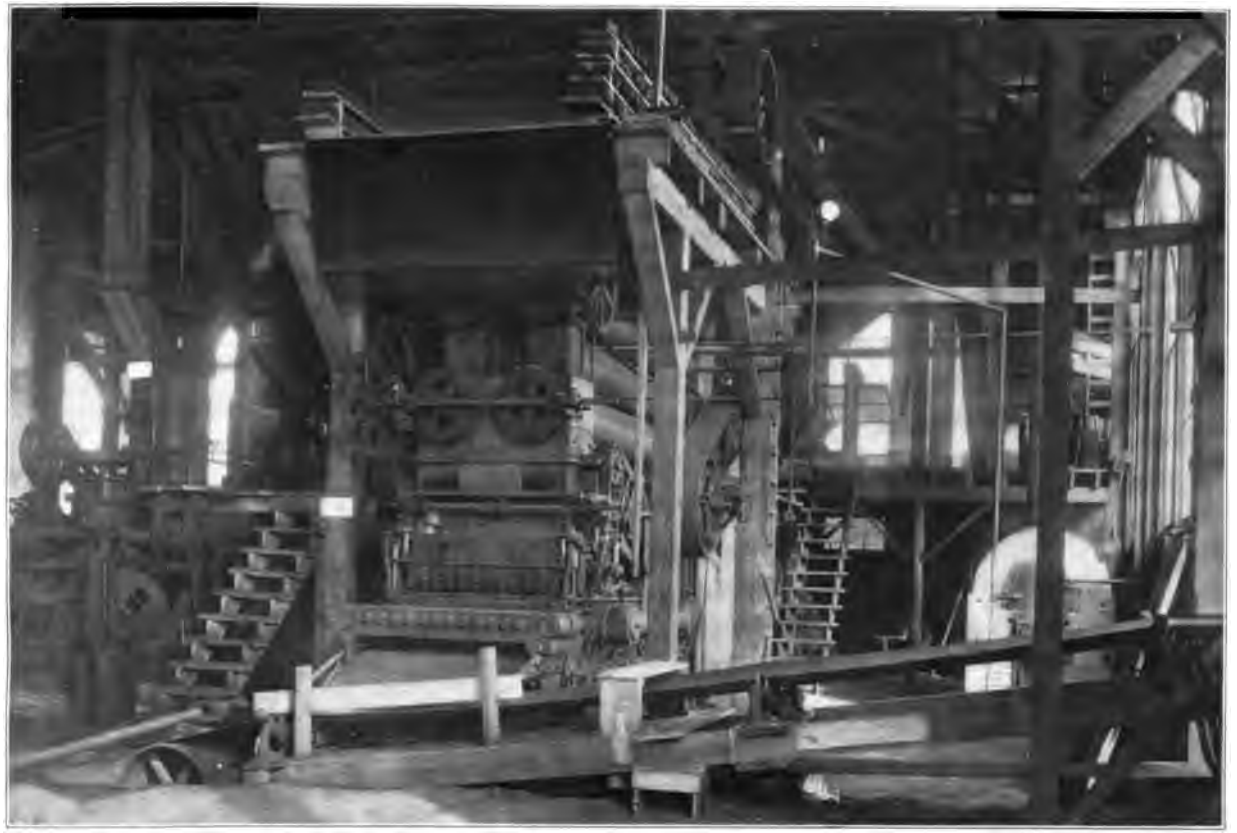
The general plan of the plant, including the location of the briquet machines, the coal-crushing machinery, and the course of some of the conveyors, is shown by Plate I.

There were three storage bins for raw fuel at the plant, two each of 25 tons capacity behind the English machine and one of 50 tons capacity behind the American machine. The samples of fuel to be tested were brought by rail over a spur track leading to the building and dumped from the car into a pit. From this pit a bucket elevator and a 16-inch belt conveyor carried the fuel to the desired storage bin. A tripper on the conveyor discharged the raw fuel into either of the bins back of the English machine or passed it on to be run into the bin back of the American machine.

Under the coal-storage bins and behind the briquet presses a floor, called the "pitch-mixing platform," was built 10 feet above the ground, and a runway 60 feet in length was provided to roll barrels of pitch up to it.



SOME AMERICAN AND FOREIGN BRIQUETS.



GENERAL VIEW OF BRIQUETTING MACHINES.

On this "pitch platform" back of each machine were scales having hoppers, into which coal could be drawn from the storage bins and weighed. Back of the English machine were other scales to weigh the pitch used as a binder. The American machine had an adjustable mechanical device (to be described later) for keeping the ratio of pitch to coal constant, so that it was not necessary to weigh the pitch used with this machine.

In addition to the conveyors that formed part of the necessary equipment for each machine there were loading belts for conveying the finished briquets from the two machines to the storage yards or to cars. One, a 30-inch Jeffrey belt conveyor 33 feet long (see Pl. III), carried the briquets from the front of the machine to the outside of the building, while the other, a 24-inch Robbins belt conveyor 65 feet long (see Pl. IX, *B*), carried the briquets from the first conveyor and loaded them into the railroad cars. Plate IX, *A*, shows the delivery end of this conveyor. Briquets were scraped from the front conveyor to the second by a quarter-circle iron band supported above the crossing of the two conveyors.

BRIQUETTING MACHINES.

NATURE AND CAPACITY.

The two briquet machines installed at Norfolk were of different types and differed radically in details of construction. The English machine was the same that was erected at the St. Louis plant at the time of the Louisiana Purchase Exposition and used in the briquetting tests at that place. It was built by William Johnson & Son, of Leeds, England, and is one of the standard types of machines for briquetting with stiff pitch. It consists of a closed-mold double-compression vertical-table press, forming two briquets at each stroke. As originally installed at St. Louis, the press had molds that formed rectangular briquets, measuring 6¾ by 5½ by 4¼ inches, with rounded corners, that weighed on the average 6.8 pounds each. The maximum capacity was 6 tons of briquets per hour. To obtain a briquet better adapted to the requirements of domestic use and locomotive-boiler practice the mold wheel on the machine was, in 1905, planed down so as to reduce the thickness of the briquets, and in the later tests at St. Louis and the Norfolk tests the machine turned out briquets measuring 6¾ by 4¼ by 2½ inches. Those made at Norfolk weighed about 3¾ pounds apiece. The capacity of the machine when making briquets of this size was 3.8 tons per hour.

The American briquet machine was built by the Renfrow Company. Briefly, it was a closed-mold double-acting plunger machine, forming 12 briquets at the end of each stroke or 24 at each revolution. The machine used at Norfolk was an improvement on one built by the same company and used in briquetting tests at St. Louis from May,

1906, to March, 1907, a certain weakness of design in the old machine, brought out by these tests, having been corrected in the new one. This new machine had a stronger frame to permit the use of heavier pressure; the working parts not subjected to pressure were of bronze to prevent corrosion; the dies, the cams, and the rollers were of tool steel. Provision was made in the design of the housing for the removal of any working part without dismantling the machine, and the arrangement of the die plunger and the length of spring behind the plunger were such as to reduce to a minimum the chance of a double charge entering the press and to prevent damage to the machine if one did enter.

The shape of the Renfrow briquets was cylindrical, with convex ends. They measured 3¼ by 1½ inches and weighed on an average 11 ounces. Running at 9 revolutions or 18 strokes per minute, the capacity of the machine was about 8.9 tons per hour.

The appearance of both machines from the front is shown by Plate III, while a side view of the English machine appears in Plate IV.

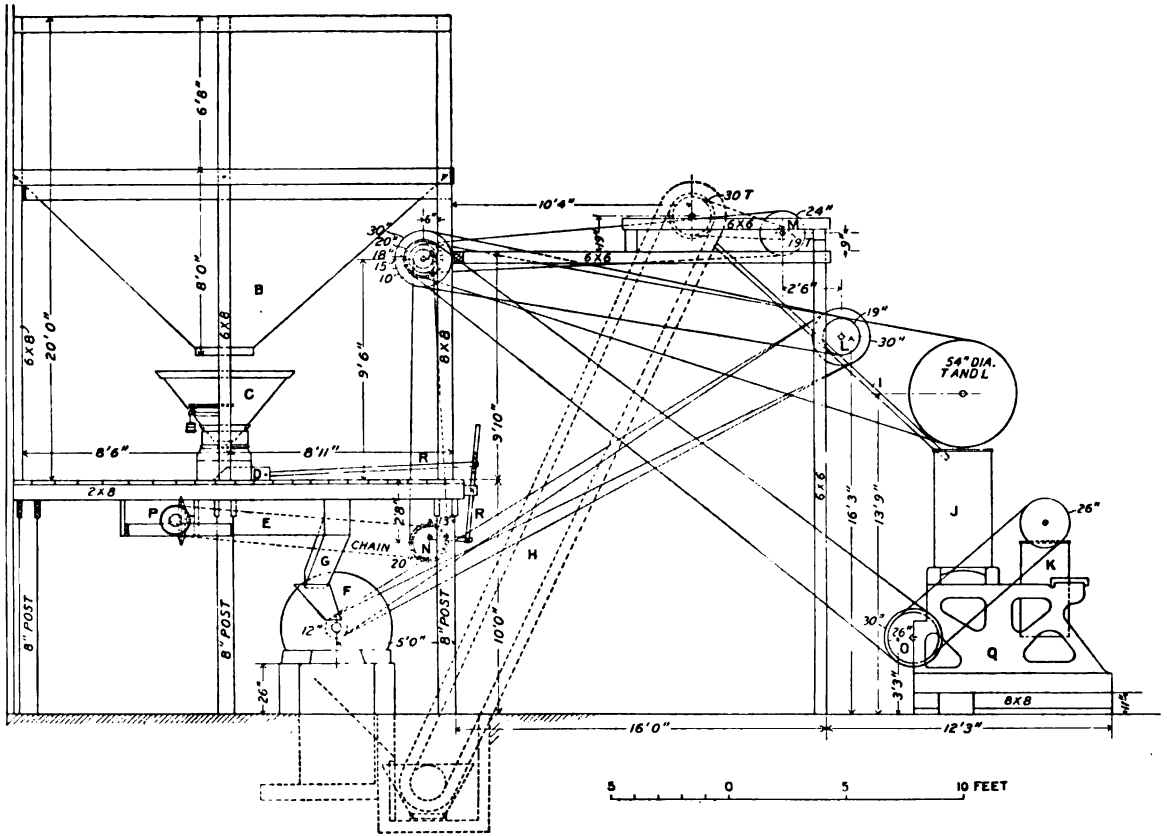
DETAILED DESCRIPTIONS.

English machine.—The position of the English machine with reference to the American machine and the coal-grinding equipment at the Norfolk plant is shown in Plate I. Plate V, an elevation of the machine, gives further details, showing the coal-storage bin, the mixing platform and coal-weighing scales, the coal breaker, various chutes, the main elevator, and the driving pulleys and belts.

The scales back of the English machine (see Pl. VI, *A*, and C, Pl. V) were placed about 6 inches above the floor to allow room for a square wooden plunger sheathed with sheet iron (D, Pl. V) to work back and forth under them and push the weighed fuel into a hole in the floor in front. The plunger was operated by a lever and connecting rod (R, Pl. V) from a crank on the jack shaft (N, Pl. V) below the mixing floor, and the jack shaft was driven by a belt and pulleys from the main shaft (A, Pl. V).

Fastened to the under side of the floor was a horizontal worm conveyor (E, Pl. V) to carry the fuel and pitch from the scales to a chute leading to the Stedman disintegrator (Pl. VI, *B*, and F, Pl. V). This conveyor was driven by a bevel-geared sprocket (P, Pl. V) and chain from the same jack shaft that worked the plunger. The conveyor delivered the material into the chute (G, Pl. V). Suspended in this chute was a powerful electro-magnet (Pl. VI, *B*) intended to pick up any pieces of iron or steel that might be in the stream of material, and prevent them from causing damage to the disintegrator or the press. The two sets of hammers in the disintegrator revolved in opposite directions at 790 revolutions per minute and were driven from the jack shaft (L, Pl. V) above and back of the briquet machine, which in turn was driven from the main shaft (A, Pl. V).

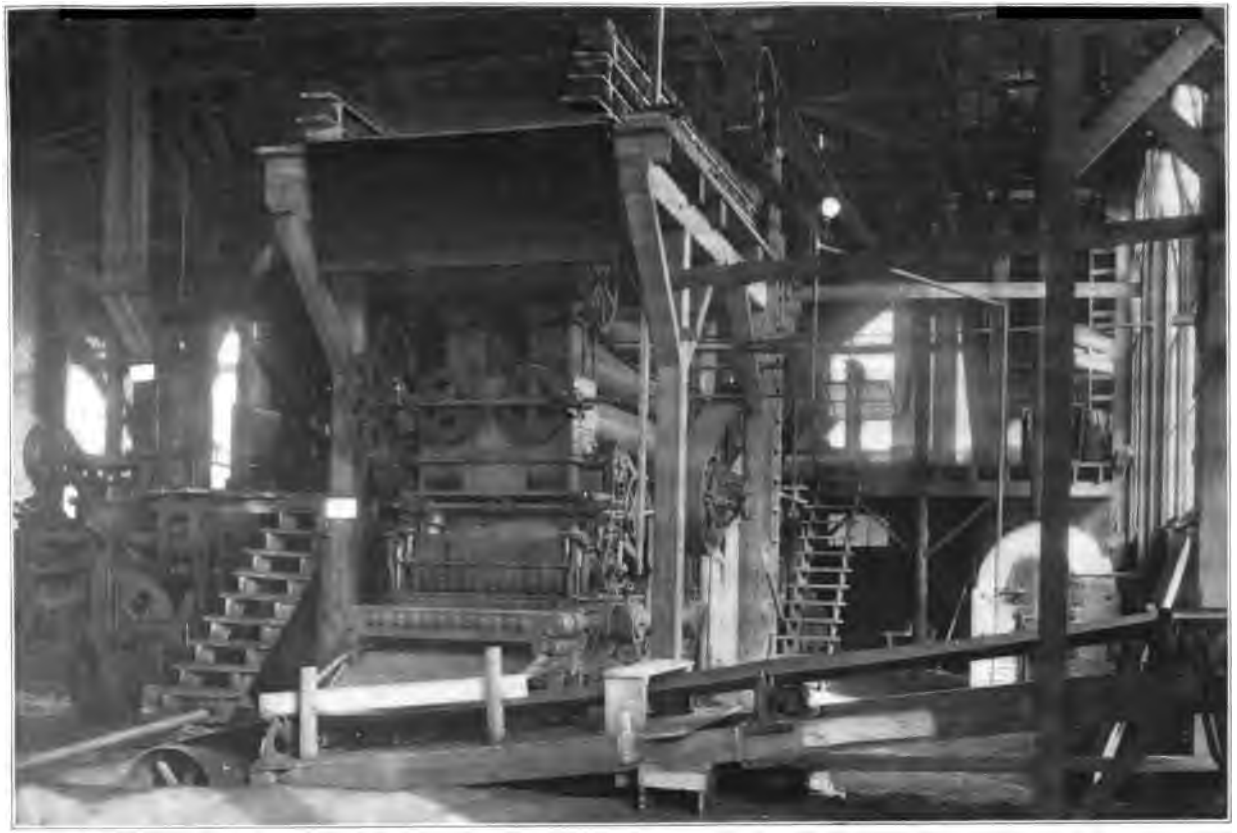
SIDE VIEW OF ENGLISH BRIQUETTING MACHINE.



ELEVATION OF ENGLISH BRIQUETTING MACHINE.

A. HOPPER AND SCALES BACK OF ENGLISH MACHINE.

B. STEDMAN DISINTEGRATOR.



GENERAL VIEW OF BRIQUETTING MACHINES.

No steam jacket was used on this machine. With very dry fuel, it was often found advantageous to add water to the mixture.

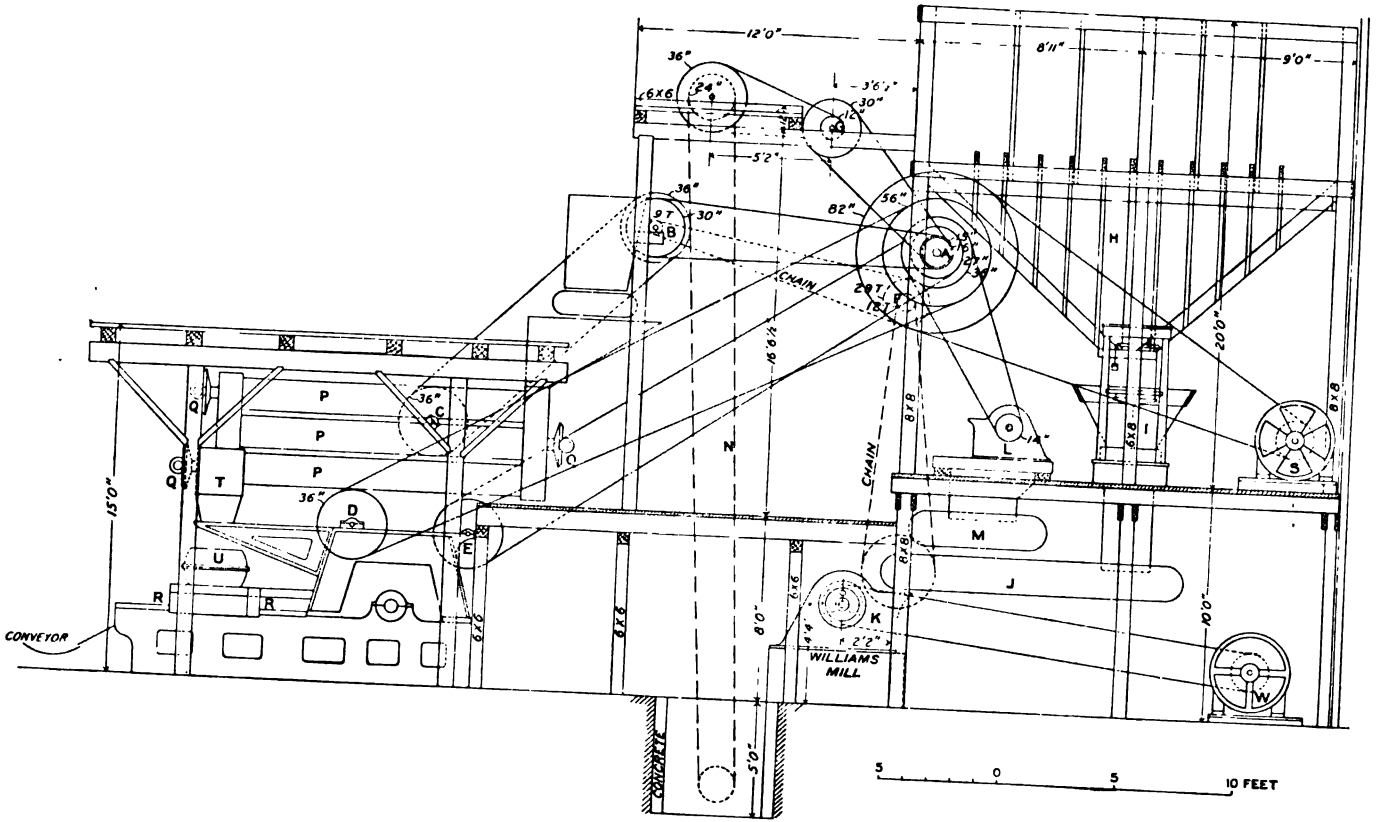
After the fuel and binder were thoroughly mixed and properly heated the mass became more or less plastic according to its briquetting qualities, and was drawn off through a door in the lower part of the cylinder into another cylinder, the feed box, set lower in the machine. From the feed box the mixture was forced by a plunger into the molds in the vertical revolving table of the press. The plunger speed was 17 strokes per minute, 1 stroke for each revolution. At half a revolution the mass in the mold was pressed by a system of levers from each end, the maximum pressure being about 2,500 pounds per square inch. Two briquets were formed at each stroke or 34 briquets per minute.

The finished briquets were removed from the machine by hand and either stacked near the machine or placed on the conveyor in front of the American machine, and by it loaded directly into a car, if one was available. They were of rectangular shape, with molded corners, and were 6¾ inches long, 4¼ inches wide, and 2½ inches thick. Their average weight was about 3¾ pounds. The maximum capacity of the machine was about 30 tons per eight-hour day.

When the machine had reached a uniform condition of working, the operator took the temperature of the briquet mixture and the temperature of the finished briquets.

American machine.—The location of the storage bin, mixing platform, coal crusher, conveyor, and the pulleys and belting that drove the press and the various accessories are shown in Plate VII, the location of the machine with reference to the English machine in Plate I and a front view of the machine in Plate III.

The American machine equipment included a bin of 50 tons capacity (H, Pl. VII), situated above and behind it; hopper scales (I, Pl. VII, and Pl. VIII, *A*); pitch cracker (L, Pl. VII, and Pl. VIII, *A*), driven by pulleys and belt from main shaft (A, Pls. V and VII); a hopper with adjustable slides in the bottom at the coal scales and over the apron conveyor (J, Pl. VII), this conveyor being driven by a chain and sprockets from the jack shaft (F, Pl. VII), which took power from main shaft (A, Pl. VII); an apron conveyor for the cracked pitch (M, Pl. VII), taking power from jack shaft (F, Pl. VII); a Williams mill (K, Pl. VII), driven by a belt from the 20-horsepower electric motor (W, Pl. VII); and a bucket elevator (N, Pl. VII), operated by chain and sprocket from the countershaft (G, Pl. VII), which in turn was driven through belt and pulleys by the main shaft (A, Pl. VII). The machine itself included steam-jacketed cylinders (PPP, Pl. VII) for heating and mixing the fuel and binder; worm conveyors driven by bevel gears (QQQ, Pl. VII), which took power from countershaft (C, Pl. VII), which in turn was driven by a belt from countershaft (B, Pl. VII), for forcing the mixture through the cylinders; a feed box



ELEVATION OF AMERICAN BRIQUETTING MACHINE.

A. PITCH CRACKER AND SCALES AND HOPPER BACK OF AMERICAN MACHINE.

B. ARRANGEMENT AND DRIVING GEAR OF PITCH AND COAL MIXING CONVEYORS.

A. CAR-LOADING CONVEYOR FILLING CAR WITH BRIQUETS.

B. PLANT END OF CAR-LOADING CONVEYOR, SHOWING CROSS CONVEYOR.

(T, Pl. VII); a die filler (U, Pl. VII); and a conveyor, not shown in Plate VII, for bringing the briquets to the front of the machine, all of which were driven by the countershaft (E, Pl. VII), which took power through pulleys and belt from main shaft (A); and a double-acting press (R, Pl. VII) operated by a drive pulley (D, Pl. VII), driven from the main shaft (A).

The main shaft (A), which furnished power to the American or to the English machine, was driven by a belt from the 50-horsepower electric motor (S, Pl. VII). The English machine required about 25 horsepower and the American machine about 50 horsepower. The 50-horsepower motor drove the English machine and its equipment; it drove the American equipment except the Williams mill.

For a test on the American machine sufficient fuel to fill the hopper on the scales (Pl. VIII, *A*) was drawn from the storage bin and weighed, the slide at the bottom of the scales was opened, and the fuel passed through a hole in the floor of the pitch platform into a hopper over the apron conveyor. A sliding door on the side of the hopper facing the direction in which the conveyor was moving could be raised or lowered to vary the thickness of the layer of fuel on the conveyor.

Pitch broken by hand into lumps was fed into the pitch cracker (Pl. VIII, *A*). The pulverized pitch fell into a hopper similar to the fuel hopper and having like it an adjustable door in one side. The apron conveyor under the pitch hopper carried away from it a layer of pitch which was discharged in an even layer upon the fuel lying on the fuel conveyor below. Plate VIII, *B*, shows the arrangement of these conveyors. The fuel and pitch fell from the fuel conveyor into the Williams mill, which reduced them to a mixture of small pieces and dust. The bucket elevator raised the ground fuel and binder from the Williams mill and dumped them into the hopper above the American briquet machine. The screw conveyors moved the material flowing from the hopper through the three pairs of horizontal steam-jacketed drums, in which the fuel and binder were suitably heated and thoroughly mixed. To heat the mixture and also to supply moisture if needed, steam was let into the drums, this steam being either saturated or superheated according to the softening point of the binder used. From the drums the heated briquet mixture passed to the press box, whence plungers forced it into die fillers, which filled the dies or molds with proper-sized charges. Then the briquets were formed by the plungers, 12 on each side of the die holder, pressing the mixture into the molds under an average pressure of 1,000 pounds per square inch. The speed of the plunger was 18 strokes per minute, making the capacity 216 briquets. On the return strokes the briquets were discharged from the molds and dropped on a conveyor which carried them to the front of the machine and dumped them on the belt conveyor (Pl. I), which carried them to the storage bin or

the railroad car. The capacity of the American machine, on the average, was 71 tons per day.

When the machine reached uniform conditions, observations were made of the temperature of the mixture before being briquetted and the temperature of the finished briquets as they came from the machine.

DETAILS OF TESTS.

JAMESTOWN No. 2.

Sample consisted of several cars of semibituminous coal from a mine working the Pocahontas No. 3 bed, Pocahontas, Tazewell County, Va., on the Norfolk and Western Railway.

Excellent briquets were made from this coal. Those made with 6 per cent of binder (Lab. No. 5458), however, stood the cohesion tests as well as those made with 8 per cent of binder (Lab. No. 5563). The warm briquets from all four of the tests had smooth firm surfaces, and those from tests 251 and 252 fractured with difficulty. Those from tests 254 and 255 were more brittle, though not easily broken. The surface of fracture of tests 251, 252, and 254 were smooth and firm, while that of test 255 crumbled easily. The cold briquets of tests 251, 252, and 254 were excellent, had smooth firm surfaces, broke without crumbling, and the fractured surfaces were smooth and firm. The cold briquets of test 255 were rather brittle, fractured easily, and surface of fracture crumbled easily.

Briquet tests.

Test No.	251.	252.	254.	255.
Size of coal as used:				
Over ¼ inch ... per cent	1.3	0.1	0.0	0.0
1/16 to ¼ inch ... do	3.4	6.3	9.4	7.4
1/32 to 1/16 inch ... do	13.7	22.6	24.2	23.5
1/64 to 1/32 inch ... do	27.2	32.3	28.0	28.3
Through 1/64 inch ... do	54.4	38.7	38.4	40.8
Details of manufacture:				
Machine used	Eng.	Am.	Am.	Am.
Briquetting temperature ... °F.	192	200	204	205
Binder—				
Kind	W. G. P.	W. G. P.	W. G. P.	W. G. P.
Laboratory No. (see p. 8)	5458	5458	5563	5563
Amount ... per cent	6	6	8	6
Weight of—				
Fuel briquetted ... pounds	138,101	181,600	2,000	2,000
Briquets, average ... do	3 27	0.633	0.581	0.595
Heat value per pound—				
Coal as received ... B. t. u.	14,632	14,632	14,632	14,632
Briquets ... do	14,549	14,726	14,794	14,796
Binder ... do	16,893	16,893	16,718	16,718
Moisture in briquet mixture ... per cent	7.62	3.99	.....	.....
Drop test (1-inch screen):				
Held ... do	74.0	66.5	65.0	46.0
Passed ... do	26.0	33.5	35.0	54.0
Tumbler test (1-inch screen):				
Held ... do	79.0	69.0	71.0	60.5
Passed ... do	21.0	31.0	29.0	39.5
Fines through 10-mesh sieve ... do	93.4	95.5	95.2	95.5
Weathering test:				
Time exposed ... days	171	178	161	161
Condition	A	A	A	B
Water absorption:				
Time immersed ... days	30	21	21	21
Water absorbed ... per cent	15.38	14.02	15.46	16.62
Average for first four days ... do	2.04	2.74	2.78	3.29
Specific gravity (apparent)	1.097	1.108	1.101	1.086

Chemical analyses of briquets.

Test No.		251.	252.	254.	255.
Laboratory No.		5466	5454	5455	5457
Proximate:					
Moisture	per cent	2.45	1.64	1.60	1.40
Volatile matter	do	18.52	19.73	19.70	19.88
Fixed carbon	do	72.79	72.65	73.08	73.22
Ash	do	6.24	5.98	5.62	5.50
Sulphur	do	.63	.61	.50	.58
Ultimate:					
Hydrogen	do	4.53	4.62	4.76	4.32
Carbon	do	80.63	83.47	84.56	83.62
Nitrogen	do	.84	.87	.97	.89
Oxygen	do	4.19	4.45	3.59	5.09

Extraction analyses.

		Pitches.		Fuel.	Briquets.			
				J-2.	Test 251.	Test 252.	Test 254.	Test 255.
Laboratory No.		5458	5563	5333	5466	5454	5455	5457
Air-drying loss	per cent	0	0	1.20	1.80	1.10	1.10	0.90
Extracted by CS_2:								
Air dried	do	92.92	90.33	.564	5.946	5.808	7.74	5.92
As received	do	92.92	90.33	.557	5.830	7.745	7.65	5.87
Pitch in briquet as received	do				5.71	5.62	7.90	5.92

JAMESTOWN No. 3.

Sample consisted of two cars of semibituminous run-of-mine coal from a mine working the "Thin Vein" Pocahontas bed, Davy, McDowell County, W. Va., on the Norfolk and Western Railway.

Excellent briquets were made on the English machine with this coal and 6 per cent of binder (Lab. No. 5458), and good briquets were made on the American machine with the same coal and binder. The briquets made on the American machine (test No. 257), with 7 per cent of binder (Lab. No. 5563), also had a good appearance but were not so strong as those from the other two tests.

Briquets from test No. 253, while warm, had a smooth surface and metallic luster and no cracks, but were easily crushed in the hand. When cold, however, they had a fine metallic ring when struck, a firm fine-grained surface, broke with difficulty and with a firm, fine-grained, lustrous fracture.

Briquets from test No. 256, while warm, had a smooth surface, were plastic, and broke with a rough fractured surface. When cold, these briquets had rough ends, broke without slacking, and had a smooth and glossy fracture.

Briquets from test No. 257 hardened at a rather high temperature, and fractured with difficulty. When cold, these briquets had a firm smooth surface, were somewhat brittle, and formed some slack when broken.

Briquet tests.

Test No.	253.	256.	257.
Size of coal as used:			
Over ¼ inch ... per cent	0.8	.....	0.1
1/16 to ¼ inch ... do	3.5	.....	6.1
1/32 to 1/16 inch ... do	14.7	.....	28.8
1/64 to 1/32 inch ... do	27.0	.....	29.5
Through 1/64 inch ... do	54.0	.....	35.5
Details of manufacture:			
Machine used	Eng.	Am.	Am.
Briquetting temperature ... °F	202	204	205
Binder—			
Kind	W. G. P.	W. G. P.	W. G. P.
Laboratory No. (see p. 8)	5458	5458	5563
Amount ... per cent	6	6	7
Weight of—			
Fuel briquetted ... pounds	24,600	12,000	10,000
Briquets, average ... do	3.53	0.617	0.588
Heat value per pound—			
Coal as received ... B. t. u.	14,443	14,443	14,443
Briquets ... do	14,828	14,728	14,836
Binder ... do	16,893	16,893	16,718
Moisture in briquet mixture ... per cent	6.09	2.71	4.91
Drop test (1-inch screen):			
Held ... do	76.4	62.0	37.5
Passed ... do	23.6	38.0	62.5
Tumbler test (1-inch screen):			
Held ... do	71.8	58.5	47.5
Passed ... do	28.2	41.5	52.5
Fines through 10-mesh sieve ... do	89.7	95.0	95.0
Weathering test:			
Time exposed ... days	162	154	154
Condition	A	B	B
Water absorption:			
Time immersed ... days	30	21	21
Water absorbed ... per cent	12.02	14.46	15.79
Average for first four days ... do	2.04	2.71	3.12
Specific gravity (apparent)	1.143	1.121	1.101

Chemical analyses of briquets.

Test No.	253.	256.	257.
Laboratory No.	5477	5478	5743
Proximate:			
Moisture ... per cent	1.86	1.69	1.06
Volatile matter ... do	17.26	18.40	17.30
Fixed carbon ... do	75.54	74.26	76.13
Ash ... do	5.34	5.65	5.51
Sulphur ... do	.66	.64	.65
Ultimate:			
Hydrogen ... do	4.58	4.61	4.70
Carbon ... do	83.87	83.87	85.15
Nitrogen ... do	1.07	1.09	1.09
Oxygen ... do	4.48	4.14	2.90

Extraction analyses.

	Pitches.		Fuel.	Briquets.		
			J-3.	Test 253.	Test 256.	Test 257.
Laboratory No.	5458	5563	5459	5477	5478	5743
Air-drying loss ... per cent	0	0	0.90	1.30	1.20	0.70
Extracted by CS_2:						
Air dried ... do	92.92	90.33	.47	5.086	5.33	5.90
As received ... do	92.92	90.33	.466	5.025	5.28	5.86
Pitch in briquet as received ... do	.....	.....	.....	4.93	5.20	6.00

JAMESTOWN No. 5.

Sample consisted of two cars of semibituminous run-of-mine coal from a mine working the Sewell bed, 1 mile east of Sewell, Fayette County, W. Va., on the Chesapeake and Ohio Railway.

Of the two tests made on this coal, the briquets of test No. 258 were better than those of test No. 259. The warm briquets of test No. 258 had smooth surfaces and were difficult to fracture. The cold briquets were very hard and brittle and formed some slack when broken. The warm briquets from test No. 259 had smooth surfaces, were very plastic, and high in moisture; the cold briquets had a very hard, firm surface, and fractured without slacking.

Briquet tests.

Test No.	258.	259.
Size of coal as used:		
Over ¼ inch ... per cent	0.1	.....
1/16 to ¼ inch ... do	6.5	.....
1/32 to 1/16 inch ... do	27.0	.....
1/64 to 1/32 inch ... do	31.1	.....
Through 1/64 inch ... do	35.3	.....
Details of manufacture:		
Machine used	Am.	Am.
Briquetting temperature ... °F	199	200
Binder—		
Kind	W. G. P.	W. G. P.
Laboratory No. (see p. 8)	5563	5458
Amount ... per cent	7	7
Weight of—		
Fuel briquetted ... pounds	136,000	2,000
Briquets, average ... do	0.568	0.588
Heat value per pound—		
Coal as received ... B. t. u.	14,522	14,522
Briquets ... do	14,542	.....
Binder ... do	16,718	16,893
Moisture in briquet mixture ... per cent	6.14	.....
Drop test (1-inch screen):		
Held ... do	70.0	48.5
Passed ... do	30.0	51.5
Tumbler test (1-inch screen):		
Held ... do	71.5	67.5
Passed ... do	28.5	32.5
Fines through 10-mesh sieve ... do	95.5	95.2
Weathering test:		
Time exposed ... days	154	154
Condition	A	A
Water absorption:		
Time immersed ... days	21	21
Water absorbed ... per cent	14.99	15.28
Average for first four days ... do	2.52	2.62
Specific gravity (apparent)	1.092	1.103

Chemical analyses of briquets.

Test No.	258.
Laboratory No.	5744
Proximate:	
Moisture ... per cent	1.32
Volatile matter ... do	24.97
Fixed carbon ... do	67.91
Ash ... do	5.80
Sulphur ... do	.63
Ultimate:	
Hydrogen ... do	4.90
Carbon ... do	82.77
Nitrogen ... do	1.14
Oxygen ... do	4.76

Extraction analyses.

		Pitch.	Fuel.	Briquets.
			J-5.	Test 258.
Laboratory No		5563	5453	5744
Air-drying loss	per cent	0	2.60	0.90
Extracted by CS_2:				
Air dried	do	90.33	.514	6.68
As received	do	90.33	.514	6.62
Pitch in briquet as received	do			6.81

JAMESTOWN No. 6.

Sample consisted of two cars of semibituminous run-of-mine coal from a mine working the Sewell bed, Red Star, Fayette County, W. Va., on the Chesapeake and Ohio Railway.

The briquets made from this coal were excellent in their physical characteristics and when warm had smooth surfaces, sharp edges, and were sufficiently strong to be loaded on cars direct from the machine. When cold these briquets were hard and firm but somewhat brittle on the edges.

Briquet tests.

Test No.		260.
Size of coal as used:		
Over ¼ inch	per cent	0.8
1/16 to ¼ inch	do	3.1
1/32 to 1/16 inch	do	11.2
1/64 to 1/32 inch	do	26.3
Through 1/64 inch	do	58.4
Details of manufacture:		
Machine used		Eng.
Briquetting temperature	°F.	203
Binder—		
Kind		W. G. P.
Laboratory No. (see p. 8)		5563
Amount	per cent	6
Weight of—		
Fuel briquetted	pounds	41,400
Briquets, average	do	3.52
Heat value per pound—		
Coal as received	B. t. u.	14,783
Briquets	do	14,715
Binder	do	16,718
Moisture in briquet mixture	per cent	5.47
Drop test (1-inch screen):		
Held	do	80.2
Passed	do	19.8
Tumbler test (1-inch screen):		
Held	do	77.4
Passed	do	22.6
Fines through 10-mesh sieve	do	88.5
Weathering test:		
Time exposed	days	135
Condition		A
Water absorption:		
Time immersed	days	35
Water absorbed	per cent	13.19
Average for first four days	do	2.24
Specific gravity (apparent)		1.117

Chemical analyses of briquets.

Test No.		260.
Laboratory No.		5558
Proximate:		
Moisture	per cent	2.15
Volatile matter	do	21.87
Fixed carbon	do	71.13
Ash	do	4.85
Sulphur	do	.81
Ultimate:		
Hydrogen	do	5.09
Carbon	do	83.37
Nitrogen	do	1.53
Oxygen	do	4.35

Extraction analyses.

		Pitch.	Fuel. J-6.	Briquets. Test 260.
Laboratory No.		5563	5489	5558
Air-drying loss	per cent	0	1.50	1.50
Extracted by CS_2:				
Air dried	do	90.33	.364	5.40
As received	do	90.33	.359	5.32
Pitch in briquet as received	do			5.51

JAMESTOWN No. 7.

Sample consisted of three cars of semibituminous run-of-mine coal from a mine working the Sewell bed, Derryhale, Fayette County, W. Va., on the Chesapeake and Ohio Railway.

The briquets made on the American machine from this coal with 7 per cent of binder (Lab. No. 5563) stood the cohesion tests better than those made on the English machine with 6 per cent of the same binder. Both were excellent briquets, gave fine metallic rings when struck, had smooth firm surfaces, broke with difficulty, and had a firm and glossy fracture.

Briquet tests.

Test No.		261.	262.
Size of coal as used:			
Over ½ inch	per cent	3.0	0.3
1/16 to ½ inch	do	6.9	6.0
1/32 to 1/16 inch	do	10.8	25.1
1/64 to 1/32 inch	do	22.4	29.3
Through 1/64 inch	do	56.9	39.3
Details of manufacture:			
Machine used		Eng.	Am.
Briquetting temperature	°F.	198	193
Binder—			
Kind		W. G. P.	W. G. P.
Laboratory No. (see p. 8)		5563	5563
Amount	per cent	6	7
Weight of—			
Fuel briquetted	pounds	43,200	38,000
Briquets, average	do	3.53	.617
Heat value per pound—			
Coal as received	B. t. u.	14,465	14,465
Briquets	do	14,886	14,717
Binder	do	16,718	16,718
Moisture in briquet mixture	per cent	5.48	4.71

Briquet tests—Continued.

Test No.		261.	262.
Drop test (1-inch screen):			
Held	per cent	69.3	71.0
Passed	do	30.7	29.0
Tumbler test (1-inch screen):			
Held	do	74.0	80.5
Passed	do	26.0	19.5
Fines through 10-mesh sieve	do	88.6	95.2
Weathering test:			
Time exposed	days	132	132
Condition		A	B
Water absorption:			
Time immersed	days	35	11
Water absorbed	per cent	11.09	12.21
Average for first four days	do	2.14	2.85
Specific gravity (apparent)		1.139	1.029

Chemical analyses of briquets.

Test No.		261.	262.
Laboratory No.		5583	5559
Proximate:			
Moisture	per cent	2.70	0.93
Volatile matter	do	20.28	18.52
Fixed carbon	do	72.74	74.65
Ash	do	4.28	5.90
Sulphur	do	.81	.81
Ultimate:			
Hydrogen	do	4.94	4.75
Carbon	do	83.75	83.67
Nitrogen	do	1.45	1.50
Oxygen	do	4.77	3.37

Extraction analyses.

		Pitch.	Fuel.	Briquets.	
			J-7.	Test 261.	Test 262.
Laboratory No.		5563	5501	5583	5559
Air-drying loss	per cent	0	1.40	2.10	0.30
Extracted by CS_2:					
Air dried	do	90.33	.410	5.094	6.58
As received	do	90.33	.404	4.990	6.56
Pitch in briquet as received	do			5.12	6.85

JAMESTOWN No. 8.

Sample consisted of two cars of semibituminous run-of-mine coal from a mine working the Quinnimont (Fire Creek) bed, Lawton, Fayette County, W. Va., on the Chesapeake and Ohio Railway.

This coal was briquetted with binders as follows: Tests 263, 264, and 270 with flour binder alone; test 271 with water-gas pitch alone; and the remaining tests, Nos. 265, 266, 267, 268, and 269, with various mixtures of flour and water-gas pitch.

All the briquets made with flour alone disintegrated very rapidly on exposure to the weather, and one sample (from test No. 270) crumbled to slack when handled after being immersed in water for

twenty-four hours. The briquets made with 1 per cent of flour binder were not strong enough to be satisfactory, but all the other briquets made with flour alone or with a mixture of flour and water-gas pitch stood the cohesion tests better than the briquets which had only water-gas pitch for a binder. A comparison of tests 267, 268, and 269 with test 271 shows that in the first three tests the drop and tumbler percentages are higher than in the fourth test. All briquets containing any flour soon became covered with a green mold when stored in a damp place and lost strength, but those stored in a dry place developed no mold, and even after eight months were apparently as good as when first made. In making briquets with flour alone, some difficulty was experienced from the briquets sticking to the dies of the press, but it is probable that when the conditions are better understood this trouble may be obviated. The briquets from test No. 268 were the strongest of the nine tests made on this coal, but those from test No. 269 were almost as strong. The briquets made with 7 per cent of water-gas pitch alone (test No. 271) were of excellent quality, but were somewhat sticky when hot, although they loaded into the car direct from the machine with very little breakage. No samples were taken for sizing tests and chemical analyses from tests 263 to 270, inclusive, as all these tests were of a preliminary nature.

Briquet tests.

Test No.	263.	264.	270.	265.	266.
Details of manufacture:					
Machine used	Am.	Eng.	Am.	Eng.	Eng.
Briquetting temperature ....°F.	198	201	.....	201	.....
Binder—					
Kind	Flour.	Flour.	Flour.	Flour W. G. P.	Flour W. G. P.
Laboratory No. (see p. 8)	6110	6110	6110	Fl. 6110 W. G. P. 5939	Fl. 6110 W. G. P. 5939
Amount ....per cent.	1.0	2.0	4	1 Flour 3 W. G. P.	2 Flour 2 W. G. P.
Weight of—					
Fuel briquetted ....pounds.	500	500	500	500	500
Briquets, average ....do.	0.558	3.55	0.595	3.47	3.55
Heat value per pound—					
Coal as received ....B. t. u.	14,701	14,701	14,701	14,701	14,701
Binder ....do.	6,998	6,998	6,998	6,998 Fl. 16,781 W. G. P.	6,998 Fl. 16,781 W. G. P.
Moisture in briquet mixture ....per cent.	.....	.....	7.29	.....	.....
Drop test (1-inch screen):					
Held ....do.	65.5	60.2	79.5	60.2	76.1
Passed ....do.	34.5	39.8	20.5	39.8	23.9
Tumbler test (1-inch screen):					
Held ....do.	31.9	56.0	89.0	67.2	75.6
Passed ....do.	68.1	44.0	11.0	32.8	24.4
Fines through 10-mesh sieve ....do.	92.7	92.0	96.0	94.0	89.2
Weathering test:					
Time exposed ....days.	132	132	132	132	132
Condition	E	E	E	C	D
Water absorption:					
Time immersed ....days.	8	9	1	8	4
Water absorbed ....per cent.	5.94	9.76	10.60	9.31	10.29
Average for first four days ....do.	1.53	2.44	(a)	2.31	2.57
Specific gravity (apparent)	1.222	1.184	1.079	1.168	1.157

[a] Sample crumbled after one day's immersion.

Briquet tests—Continued.

Test No.	267.	268.	269.	271.
Size of coal as used:				
Over ¼ inch ... per cent				0.0
1/16 to ¼ inch ... do				9.3
1/32 to 1/16 inch ... do				35.5
1/64 to 1/32 inch ... do				29.2
Through 1/64 inch ... do				28.0
Details of manufacture:				
Machine used	Am.	Am.	Am.	Am.
Briquetting temperature ... °F				196
Binder—				
Kind	Flour W. G. P.	Flour W. G. P.	Flour W. G. P.	W. G. P.
Laboratory No. (see p. 8)	Fl. 6110 W. G. P 5941	Fl. 6110 W. G. P. 5941	Fl. 6110 W. G. P. 5941	5941
Amount ... per cent	2 Flour 2 W. G. P.	2 Flour 3 W. G. P.	2 Flour 2 W. G. P.	7
Weight of—				
Fuel briquetted ... pounds	500	500	500	81,250
Briquets, average ... do	0.562	0.588	0.562	0.633
Heat value per pound—				
Coal as received ... B. t. u.	14,701	14,701	14,701	14,701
Briquets ... do				14,584
Binder ... do				16,978
Moisture in briquet mixture ... per cent		6.29	5.72	5.21
Drop test (1-inch screen):				
Held ... do	84.0	87.0	84.5	46.5
Passed ... do	16.0	13.0	15.5	53.5
Tumbler test (1-inch screen):				
Held ... do	81.0	91.0	88.0	58.0
Passed ... do	19.0	9.0	12.0	42.0
Fines through 10-mesh sieve ... do	95.7	96.7	97.0	95.5
Weathering test:				
Time exposed ... days	132	132	132	127
Condition	E	B	C	A
Water absorption:				
Time immersed ... days	4	5	4	12
Water absorbed ... per cent	11.47	8.09	16.56	15.31
Average for first four days ... do	2.87	2.00	4.14	3.56
Specific gravity (apparent)	1.150	1.196	1.087	1.100

Chemical analyses of briquets.

Test No.	271.
Laboratory No.	5713
Proximate:	
Moisture ... per cent	3.28
Volatile matter ... do	18.50
Fixed carbon ... do	73.44
Ash ... do	4.78
Sulphur ... do	.84
Ultimate:	
Hydrogen ... do	4.95
Carbon ... do	82.26
Nitrogen ... do	1.07
Oxygen ... do	6.10

Extraction analyses.

	Pitch.	Fuel.	Briquets.
		J-8.	Test 271.
Laboratory No.	5941	5575	5713
Air-drying loss ... per cent	0	2.20	2.90
Extracted by CS_2:			
Air dried ... do	98.44	.534	4.94
As received ... do	98.44	.523	4.80
Pitch in briquet as received ... do			4.38

JAMESTOWN No. 9.

Sample consisted of two cars of semibituminous run-of-mine coal from a mine working the Sewell bed, Winona, Fayette County, W. Va., on the Chesapeake and Ohio Railway.

This coal was briquetted with three different kinds of binders. The briquets from test No. 274 made with water-gas pitch (Lab. No. 5939) were the strongest of the three. All three tests made excellent briquets, which gave good metallic rings when knocked together, had smooth, hard surfaces, were broken with difficulty, and had firm and glossy fractured surfaces.

Briquet tests.

Test No.	272.	273.	274.
Size of coal as used:			
Over ¼ inch ... per cent	0.0	.....	.....
1/16 to ¼ inch ... do	7.9	.....	.....
1/32 to 1/16 inch ... do	22.9	.....	.....
1/64 to 1/32 inch ... do	30.5	.....	.....
Through 1/64 inch ... do	37.1	.....	.....
Details of manufacture:			
Machine used	Am.	Am.	Am.
Briquetting temperature ... °F	195	198	198
Binder—			
Kind	W.G.P.	W.G.P.	W.G.P.
Laboratory No. (see p. 8)	5941	5563	5939
Amount ... per cent	7	7	7
Weight of—			
Fuel briquetted ... pounds	46,000	2,000	2,000
Briquets, average ... do	0.625	0.602	0.610
Heat value per pound—			
Coal as received ... B. t. u.	14,238	14,238	14,238
Briquets ... do	14,699	.....	.....
Binder ... do	16,978	16,718	16,781
Moisture in briquet mixture ... per cent	5.65	.....	.....
Drop test (1-inch screen):			
Held ... do	57.5	71.0	73.0
Passed ... do	42.5	29.0	27.0
Tumbler test (1-inch screen):			
Held ... do	64.0	77.0	83.5
Passed ... do	36.0	23.0	16.5
Fines through 10-mesh sieve ... do	95.1	96.7	96.6
Weathering test:			
Time exposed ... days	125	52	125
Condition	A	A	A
Water absorption:			
Time immersed ... days	12	21	13
Water absorbed ... per cent	16.66	13.02	13.14
Average for first four days ... do	3.49	2.75	2.79
Specific gravity (apparent)	1.072	1.118	1.117

Chemical analyses of briquets.

Test No.	272.
Laboratory No.	5745
Proximate:	
Moisture ... per cent	2.64
Volatile matter ... do	25.29
Fixed carbon ... do	67.61
Ash ... do	4.46
Sulphur ... do	.65
Ultimate:	
Hydrogen ... do	5.16
Carbon ... do	82.34
Nitrogen ... do	1.11
Oxygen ... do	6.28

Extraction analyses.

	Pitches.		Fuel.	Briquets.
			J-9.	Test 272.
Laboratory No.	5941	5939	5709	5745
Air-drying loss ... per cent	0	0	3.00	2.10
Extracted by CS_2:				
Air dried ... do	98.44	98.13	.706	4.78
As received ... do	98.44	98.13	.685	4.77
Pitch in briquet as received ... do				4.18

JAMESTOWN No. 10.

Sample consisted of two cars of semibituminous run-of-mine coal from a mine working the Beckley bed, Stanaford, Raleigh County, W. Va., on the Chesapeake and Ohio Railway.

Test 275 gave a satisfactory briquet with 6 per cent of water-gas pitch (Lab. No. 5941). The briquets had smooth, firm surfaces, sharp edges, were broken with difficulty, and had firm and glossy fracture surfaces.

Briquet tests.

Test No.	275.
Size of coal as used:	
Over ¼ inch ... per cent	4.5
1/16 to ¼ inch ... do	16.0
1/32 to 1/16 inch ... do	28.8
1/64 to 1/32 inch ... do	25.4
Through 1/64 inch ... do	25.3
Details of manufacture:	
Machine used	Eng.
Briquetting temperature ... °F	182
Binder—	
Kind	W. G. P.
Laboratory No. (see p. 8)	5941
Amount ... per cent	6
Weight of—	
Fuel briquetted ... pounds	53,550
Briquets, average ... do	3.83
Heat value per pound—	
Coal as received ... B. t. u.	14,024
Briquets ... do	13,871
Binder ... do	16,978
Moisture in briquet mixture ... per cent	6.45
Drop test (1-inch screen):	
Held ... do	33.7
Passed ... do	66.3
Tumbler test (1-inch screen):	
Held ... do	55.0
Passed ... do	45.0
Fines through 10-mesh sieve ... do	90.0
Weathering test:	
Time exposed ... days	120
Condition	A
Water absorption:	
Time immersed ... days	21
Water absorbed ... per cent	8.75
Average for first four days ... do	2.07
Specific gravity (apparent)	1.203

Chemical analyses of briquets.

Test No.		275.
Laboratory No.		5746
Proximate:		
Moisture	per cent	3.83
Volatile matter	do	18.69
Fixed carbon	do	69.03
Ash	do	8.45
Sulphur	do	.91
Ultimate:		
Hydrogen	do	4.88
Carbon	do	78.21
Nitrogen	do	1.19
Oxygen	do	6.36

Extraction analyses.

		Pitch.	Fuel. J-10.	Briquets. Test 275.
Laboratory No.		5941	5719	5746
Air-drying loss	per cent	0	1.40	3.40
Extracted by CS_2:				
Air dried	do	98.44	.652	5.25
As received	do	98.44	.643	5.07
Pitch in briquet as received	do			4.53

JAMESTOWN No. 11.

Sample consisted of two cars of semibituminous run-of-mine coal from a mine working the Beckley bed, West Raleigh, Raleigh County, W. Va., on the Chesapeake and Ohio Railway.

Test No. 276. Excellent briquets were made from this coal with 7 per cent of water-gas pitch (Lab. No., 5941).

Test No. 277. Six tons of briquets were made on the English machine from this coal with 3 per cent of flour for a binder. These briquets were strong even after standing for three months in a damp place, and samples of them which have been kept in a dry place for seven months appear as good as when first made. After exposure to the weather for six weeks in the winter time, a sample of the briquets could be handled and was still serviceable, so that it would seem that flour may be considered a satisfactory binder when the briquets made from it are not exposed to the weather for more than two months.

Test No. 289. In order to compare flour and pitch binders, 6 tons of this coal was briquetted with 6 per cent of water-gas pitch (Lab. No., 5940), and an excellent briquet was obtained. A comparison of the briquets from this test with those made with flour binder (test No. 277) shows that the flour briquets were stronger by physical tests but did not resist the effects of weathering as well as the pitch briquets.

Test No. 290. A mixture of 50 per cent of Jamestown No. 11 and 50 per cent of anthracite coal (buckwheat size), designated as Jamestown No. 18, was made to see if fine anthracite could be improved by briquetting with a bituminous coal. A very satisfactory briquet was obtained which had a firm smooth surface, was hard to break, and firm, hard, and glossy fracture surfaces.

Briquet tests.

Test No.	276.	277.	289.	290.[a]
Size of coal as used:				
Over ¼ inch ... per cent	0.1	.....	0.4	5.7
1/16 to ¼ inch ... do	7.4	.....	4.2	17.2
1/32 to 1/16 inch ... do	29.9	.....	23.2	19.6
1/64 to 1/32 inch ... do	27.7	.....	39.6	18.9
Through 1/64 inch ... do	34.9	11.41	32.6	38.6
Details of manufacture:				
Machine used	Am.	Eng.	Eng.	Eng.
Briquetting temperature ... °F	190	185	.....	191
Binder—				
Kind	W. G. P.	Flour.	W. G. P.	W. G. P.
Laboratory No. (see p. 8)	5941	6110	5940	5940
Amount ... per cent	7	3	6	6
Weight of—				
Fuel briquetted ... pounds	42,000	12,000	12,750	12,350
Briquets, average ... do	0.610	3.78	3.77	4.15
Heat value per pound—				
Coal as received ... B. t. u.	14,391	14,391	14,391	([b])
Briquets ... do	14,630	14,186	14,584	13,921
Binder ... do	16,978	6,998	16,780	16,780
Moisture in briquet mixture ... per cent	4.60	11.41	10.10	8.48
Drop test (1-inch screen):				
Held ... do	70.0	77.2	68.2	68.3
Passed ... do	30.0	22.8	31.8	31.7
Tumbler test (1-inch screen):				
Held ... do	77.5	60.7	72.0	78.5
Passed ... do	22.5	39.3	28.0	21.5
Fines through 10-mesh sieve ... do	94.0	88.3	88.2	87.5
Weathering test:				
Time exposed ... days	120	120	102	102
Condition	A	D	A	A
Water absorption:				
Time immersed ... days	9	5	31	31
Water absorbed ... per cent	13.45	4.43	9.82	9.85
Average for first four days ... do	3.25	1.05	1.21	1.31
Specific gravity (apparent)	1.117	1.239	1.161	1.247

[a] Jamestown No. 11, 50 per cent; Jamestown No. 18, 50 per cent.
[b] No sample for Jamestown No. 18.

Chemical analyses of briquets.

Test No.	276.	277.	289.	290.
Laboratory No.	5756	6111	6112	6113
Proximate:				
Moisture ... per cent	2.73	3.83	1.61	3.42
Volatile matter ... do	18.27	15.77	20.30	13.03
Fixed carbon ... do	73.56	74.50	71.98	75.93
Ash ... do	5.44	5.90	6.11	7.62
Sulphur ... do	.66	.69	.79	.63
Ultimate:				
Hydrogen ... do	4.72	4.40	4.12	3.77
Carbon ... do	82.83	79.43	81.25	80.77
Nitrogen ... do	1.32	.85	1.45	1.45
Oxygen ... do	5.03	8.73	6.28	6.36

Extraction analyses.

	Pitches.		Fuel.	Briquets.			
			J-11.	Test 276.	Test 277.	Test 289.	Test 290.
Laboratory No.	5941	5940	5718	5756	6111	6112	6113
Air-drying loss ... per cent	0	0	1.50	2.30	.....	0.80	2.20
Extracted by CS_2:							
Air dried ... do	98.44	96.60	.598	5.33	.....	4.67	5.37
As received ... do	98.44	96.60	.590	5.21	.....	4.63	5.25
Pitch in briquet as received ... do	.....	.....	.....	4.72	.....	4.21	5.12

JAMESTOWN No. 12.

Sample consisted of one car of bone coal from a mine working Pocahontas No. 3 bed, Switchback, McDowell County, W. Va., on the Norfolk and Western Railway.

This "bone" coal was briquetted first with 6 per cent water-gas pitch (Lab. No., 5941), and such excellent briquets were obtained that test No. 279 was made to see if 5 per cent of the same binder would make a satisfactory briquet. The 5 per cent briquet was found to be better than the 6 per cent one. Both tests made excellent briquets, which had firm, smooth surfaces, were broken with difficulty, and had firm, close-grained, and shiny fracture surfaces.

Briquet tests.

Test No.	278.	279.
Sizes of coal as used:		
Over ½ inch ... per cent	5.6	5.6
1/16 to ¼ inch ... do	18.1	18.1
1/32 to 1/16 inch ... do	33.8	33.8
1/64 to 1/32 inch ... do	23.2	23.2
Through 1/64 inch ... do	19.3	19.3
Details of manufacture:		
Machine used	Am.	Am.
Briquetting temperature ... °F	195	194
Binder—		
Kind	W. G. P.	W. G. P.
Laboratory No. (see p. 8)	5941	5941
Amount ... per cent	6	5
Weight of—		
Fuel briquetted ... pounds	38,000	16,000
Briquets, average ... do	0.676	0.709
Heat value per pound—		
Briquets ... B. t. u.	12,938	.....
Binder ... do	16,978	16,978
Moisture in briquet mixture ... per cent	5.03	.....
Drop test (1-inch screen):		
Held ... do	59.0	66.5
Passed ... do	41.0	33.5
Tumbler test (1-inch screen):		
Held ... do	72.0	78.5
Passed ... do	28.0	21.5
Fines through 10-mesh sieve ... do	90.9	93.2
Weathering test:		
Time exposed ... days	137	137
Condition	A	A
Water absorption:		
Time immersed ... days	5	4
Water absorbed ... per cent	11.73	12.18
Average for first four days ... do	2.91	3.05
Specific gravity (apparent)	1.251	1.248

Chemical analyses of briquets.

Test No		278.
Laboratory No		5856
Proximate:		
Moisture	per cent	1.71
Volatile matter	do	13.96
Fixed carbon	do	68.36
Ash	do	15.97
Sulphur	do	.42
Ultimate:		
Hydrogen	do	3.99
Carbon	do	73.14
Nitrogen	do	.77
Oxygen	do	5.71

Extraction analyses.

		Pitch.	Briquets. Test 278.
Laboratory No		5941	5856
Air drying loss	per cent	0	1.10
Extracted by CS_2:			
Air dried	do	98.44	5.74
As received	do	98.44	5.67

JAMESTOWN No. 13.

Sample consisted of three cars of semibituminous run-of-mine coal from a mine working the Pocahontas No. 3 bed, Ennis, McDowell County, W. Va., on the Norfolk and Western Railway.

This coal was briquetted on both the English and American machines for locomotive tests, and was shipped from the plant without any samples being retained, so no physical tests could be made on the briquets. In appearance, just after making, the briquets made on the English machine were very satisfactory and had firm, smooth surfaces.

Briquet tests.

Test No		286.	287.
Details of manufacture:			
Machine used		Eng.	Am.
Binder—			
Kind		W. G. P.	W. G. P.
Laboratory No. (see p. 8)		5940	5940
Amount	per cent	6	6
Weight of—			
Fuel briquetted	pounds	82,950	160,000
Heat value per pound—			
Coal as received	B. t. u.	14,290	14,746
Briquets	do	14,299	.....
Binder	do	16,780	16,780

Chemical analyses of briquets.

Test No		286.
Laboratory No		5848
Proximate:		
Moisture	per cent	3.10
Volatile matter	do	17.08
Fixed carbon	do	73.11
Ash	do	6.71
Sulphur	do	.52
Ultimate:		
Hydrogen	do	4.37
Carbon	do	80.75
Nitrogen	do	.97
Oxygen	do	6.68

Extraction analyses.

		Pitch.	Fuel, J-13.	Briquets. Test 286.
Laboratory No		5940	5829	5948
Air-drying loss	per cent	0	2.80	2.60
Extracted by CS_2:				
Air dried	do	96.60	.346	5.31
As received	do	96.60	.336	5.17
Pitch in briquet as received	do			5.02

JAMESTOWN No. 14.

Sample consisted of a car of Virginia semianthracite culm from a mine working the Big vein, Merrimac, Montgomery County, Va., on the Virginia Anthracite Railway.

The coal designated as Jamestown No. 14 was semianthracite culm, and a test was made to see if it could be briquetted into a serviceable fuel. As received it was very wet, and serious difficulty was experienced in crushing it with the Williams mill because of its tendency to pack in the mill and stop it. About 11 tons of briquets were made, however, and these were stronger than necessary when made with 8 per cent pitch binder, but were rather weak with 6 per cent; 7 per cent would probably make a satisfactory briquet. When tested in a kitchen range, these briquets did not burn with satisfactory results, but after breaking them into three or four pieces a better fire was obtained than with a good grade of anthracite coal of egg size. These briquets made a satisfactory fuel for an open-grate fire and for large heating stoves. They had a peculiar property of "banking" themselves, due to the high percentage of ash in them (22.5 per cent), and a fire could be kept over night with them even in a small kitchen range.

Briquet tests.

Test No.		291.
Size of coal as used:		
Over ½ inch	per cent	0.0
1/16 to ½ inch	do	11.9
1/32 to 1/16 inch	do	32.8
1/64 to 1/32 inch	do	24.3
Through 1/64 inch	do	31.0
Details of manufacture:		
Machine used		Am.
Briquetting temperature	°F.	187
Binder –		
Kind		W. G. P.
Laboratory No. (see p. 8)		5940
Amount	per cent	6
Weight of –		
Fuel, briquetted	pounds	22,000
Briquets, average	do	0.746
Heat value per pound –		
Coal as received	B. t. u.	9,688
Briquets	do	11,598
Binder	do	16,780
Moisture in briquet mixture	per cent	7.35
Drop test (1-inch screen):		
Held	do	16.0
Passed	do	84.0
Tumbler test (1-inch screen):		
Held	do	28.0
Passed	do	72.0
Fines through 10-mesh sieve	do	94.1
Weathering test:		
Time exposed	days	102
Condition		B
Water absorption:		
Time immersed	days	31
Water absorbed	per cent	12.76
Average for first four days	do	1.63
Specific gravity (apparent)		1.299

Chemical analyses of briquets.

Test No.		291.
Laboratory No.		6114
Proximate:		
Moisture	per cent	2.07
Volatile matter	do	9.93
Fixed carbon	do	65.48
Ash	do	22.52
Sulphur	do	.52
Ultimate:		
Hydrogen	do	3.21
Carbon	do	66.72
Nitrogen	do	.98
Oxygen	do	6.05

Extraction analyses.

		Pitch.	Fuel, J-14.	Briquets, test 291.
Laboratory No.		5940	5938	6114
Air-drying loss	per cent	0	1.60	1.10
Extracted by CS_2:				
Air dried	do	96.60	.06	5.25
As received	do	96.60	.06	5.19
Pitch in briquet as received	do			5.32

JAMESTOWN No. 15.

Sample consisted of several cars of semibituminous run-of-mine coal from a mine working the Sewell bed, Minden, Fayette County, W. Va., on the Chesapeake and Ohio Railway.

Test No. 280. Owing to the presence of an excessive amount of moisture in this coal, it was very difficult to make satisfactory briquets on the English machine. Water cracks formed, and the briquets had a porous surface which was easily rubbed off. They were easily broken, forming considerable slack. As the flowing point of the binder used in this test was 194° F., the briquetting temperature of 187° F. was not high enough to soften the pitch sufficiently to obtain the best results.

Test No. 281. The briquets which were made on the American machine were probably stronger than those of test No. 280, made on the English machine, but the sample saved for the physical tests was mislaid, making it impossible to apply the tests. The briquets were very hard and showed no water cracks, although the coal was very wet.

Briquet tests.

Test No.	280.	281.
Size of coal as used:		
Over ¼ inch ... per cent	0.1	0.0
1/16 to ¼ inch ... do	8.9	5.1
1/32 to 1/16 inch ... do	27.1	28.6
1/16 to 1/32 inch ... do	27.0	32.8
Through 1/16 inch ... do	36.9	33.5
Details of manufacture:		
Machine used	Eng.	Am.
Briquetting temperature ... °F	187	190
Binder—		
Kind	W. G. P.	W. G. P.
Laboratory No. (see p. 8)	5941	5941
Amount ... per cent	6	6
Weight of—		
Fuel briquetted ... pounds	65,800	300,000
Briquets, average ... do	3.57	0.720
Heat value per pound—		
Coal as received ... B. t. u.	14,009	14,009
Briquets ... do	14,548	14,575
Binder ... do	16,978	16,978
Moisture in briquet mixture ... per cent	7.04	6.87
Drop test (1-inch screen):		
Held ... do	19.6	.....
Passed ... do	80.4	.....
Tumbler test (1-inch screen):		
Held ... do	48.8	.....
Passed ... do	51.2	.....
Fines through 10-mesh sieve ... do	88.9	.....
Weathering test:		
Time exposed ... days	137	125
Condition	B	B
Water absorption:		
Time immersed ... days	5	11
Water absorbed ... per cent	7.87	12.01
Average for first four days ... do	1.95	2.92
Specific gravity (apparent)	1.185	1.079

Chemical analyses of briquets.

Test No.	280.	281.
Laboratory No.	5857	5859
Proximate:		
Moisture ... per cent	1.09	3.21
Volatile matter ... do	18.70	19.49
Fixed carbon ... do	73.60	72.67
Ash ... do	6.61	4.63
Sulphur ... do	.95	.68
Ultimate:		
Hydrogen ... do	4.70	4.83
Carbon ... do	80.88	81.97
Nitrogen ... do	1.20	1.27
Oxygen ... do	5.66	6.62

Extraction analyses.

	Pitch.	Fuel.	Briquets.	
		J-15.	Test 280.	Test 281.
Laboratory No.	5941	5774	5857	5859
Air drying loss ... per cent	0	3.00	0.40	2.30
Extracted by CS_2:				
Air dried ... do	98.44	.43	5.57	5.02
As received ... do	98.44	.42	5.54	5.77
Pitch in briquet as received ... do			5.22	5.46

JAMESTOWN No. 16.

Sample consisted of semibituminous run-of-mine coal from West Virginia.

This coal was briquetted with four different kinds of water-gas pitch binders, 6 per cent of each being used. Apparently the test briquets were those of test No. 285, while those of test No. 282 were practically as good. Both of these tests were made on the English machine. Test No. 283, made on the American machine, was a satisfactory briquet, but the briquets of test No. 284 made on the English machine with water-gas pitch (Lab. No. 5939) were not satisfactory, as they did not stand the physical tests well.

Tests 283 and 285 made briquets with smooth, firm, fine-grained surfaces, they broke with difficulty, and had firm and hard fracture surfaces.

Test No. 282 made good briquets as far as strength was concerned, but their surfaces were rough and coarse-grained, and their edges rubbed off somewhat easily. They broke with difficulty and the fractured surface was coarse, firm, and dull black in color.

Test No. 284 furnished very poor briquets, the surfaces of which were rubbed off easily, owing either to too small a percentage of pitch or to too low a briquetting temperature; the briquets were easily broken, and the fractured surfaces were rough and easily rubbed off.

Briquet tests.

Test No.	282.	283.	284.	285.
Size of coal as used:				
Over ½ inch ... per cent	5.0	0.1	.....	.....
1/16 to ¼ inch ... do	16.0	14.4	.....	.....
2/16 to 1/16 inch ... do	31.4	36.0	.....	.....
4/16 to 2/16 inch ... do	26.3	25.9	.....	.....
Through 4/16 inch ... do	21.3	23.6	.....	.....
Details of manufacture:				
Machine used	Eng.	Am.	Eng.	Am.
Briquetting temperature ... °F	174	189	.....	.....
Binder—				
Kind	W. G. P.	W. G. P.	W. G. P.	W. G. P.
Laboratory No. (see p. 8)	4879	5941	5939	5940
Amount ... per cent	6	6	6	6
Weight of—				
Fuel briquetted ... pounds	52,048	66,000	30,600	37,400
Briquets, average ... do	4.10	0.641	3.83	3.68
Heat value per pound—				
Coal as received ... B. t. u.	13,480	13,480	13,480	13,480
Briquets ... do	12,780	13,754	13,939	.....
Binder ... do	16,805	16,978	16,781	16,780
Moisture in briquet mixture ... per cent	9.55	7.55	.....	8.40
Drop test (1-inch screen):				
Held ... do	77.3	35.5	39.2	78.8
Passed ... do	22.7	64.5	60.8	21.2
Tumbler test (1-inch screen):				
Held ... do	82.7	56.0	47.8	82.8
Passed ... do	17.2	44.0	52.2	17.2
Fines through 10-mesh sieve ... do	88.0	90.1	90.1	89.5
Weathering test:				
Time exposed ... days	137	125	118	118
Condition	B	B	B	A
Water absorption:				
Time immersed ... days	31	31	31	31
Water absorbed ... per cent	9.79	10.55	15.98	11.23
Average for first four days ... do	0.89	1.12	1.82	1.13
Specific gravity (apparent)	1.206	1.126	1.112	1.143

Chemical analyses of briquets.

Test No.	282.	283.	284.
Laboratory No	5946	5945	5947
Proximate:			
Moisture ... per cent	2.21	2.27	2.06
Volatile matter ... do	30.97	32.56	31.65
Fixed carbon ... do	52.97	56.52	58.74
Ash ... do	13.85	8.65	7.55
Sulphur ... do	0.89	0.85	0.80
Ultimate:			
Hydrogen ... do	4.43	4.81	4.82
Carbon ... do	70.30	75.97	76.66
Nitrogen ... do	1.09	1.22	1.24
Oxygen ... do	9.44	8.50	8.93

Extraction analyses.

	Pitches.			Fuel.	Briquets.		
				J-16.	Test 282.	Test 283.	Test 284.
Laboratory No	4879	5945	5939	5828	5946	5945	5947
Air-drying loss ... per cent	0	0	0	3.40	1.20	1.40	1.20
Extracted by CS_2:							
Air dried ... do	94.50	98.44	98.13	.71	5.50	6.48	5.16
As received ... do	94.50	98.44	98.13	.68	5.43	6.39	5.10
Pitch in briquet as received ... do	.....	.....	.....	.....	5.06	5.84	4.54

JAMESTOWN No. 17.

Sample consisted of semibituminous run-of-mine coal from the Pocahontas No. 3 bed of West Virginia.

Eighty tons of this coal were briquetted for a special test on the battle ship *Connecticut* of the United States Navy, and as it was shipped without any samples being retained no data exist on which to make a report.

Briquet tests.

Test No.	288.
Details of manufacture:	
Machine used	Am.
Binder—	
Kind	W. G. P.
Laboratory No. (see p. 8)	5940
Amount ... per cent	6
Weight of—	
Fuel briquetted ... pounds	160,000
Heat value per pound—	
Coal as received ... B. t. u.	14,746
Binder ... do	16,780

Extraction analysis.

	Pitch.
Laboratory No.	5940
Air-drying loss ... per cent	0
Extracted by CS_2:	
Air dried ... do	96.60
As received ... do	96.60

JAMESTOWN No. 18.

This coal was anthracite coal of buckwheat size and was briquetted in a mixture with Jamestown No. 11 coal in test No. 290. The data obtained from this test can be found under Jamestown No. 11 coal, test No. 290.

BIBLIOGRAPHY.

SURVEY PUBLICATIONS ON FUEL TESTING.

The following publications, except those to which a price is affixed, can be obtained free by applying to the Director, Geological Survey, Washington, D. C. The priced publications can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

BULLETIN 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, in St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

PROFESSIONAL PAPER 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1,492 pp., 13 pls. $1.50.

BULLETIN 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

BULLETIN 323. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp. 10 cents.

BULLETIN 325. A study of four hundred steaming tests, made at the fuel-testing plant, St. Louis, Mo., 1904, 1905, and 1906, by L. P. Breckenridge. 1907. 196 pp.

BULLETIN 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907; J. A. Holmes, in charge. 1908. 299 pp.

BULLETIN 334. The burning of coal without smoke in boiler plants; a preliminary report, by D. T. Randall. 1908. 26 pp. 5 cents.

BULLETIN 336. Washing and coking tests of coal and cupola tests of coke, by Richard Moldenke, A. W. Belden, and G. R. Delamater. 1908. 76 pp. 10 cents.

BULLETIN 339. The purchase of coal under government and commercial specifications on the basis of its heating value, with analyses of coal delivered under government contracts, by D. T. Randall. 1908. 27 pp. 5 cents.

BULLETIN 343. Binders for coal briquets, by J. E. Mills. 1908. 56 pp.

BULLETIN 362. Mine sampling and chemical analyses of coals tested at the United States fuel-testing plant, Norfolk, Va., in 1907, by J. S. Burrows. 1908. 23 pp.

BULLETIN 363. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests and some foreign specifications for briquetted fuel, by W. F. M. Goss. 1908. 57 pp., 4 pls.

BULLETIN 366. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 1908. 44 pp., 3 pls.

BULLETIN 367. Significance of drafts in steam-boiler practice, by W. T. Ray and Henry Kreisinger. 1909. 61 pp.

BULLETIN 368. Washing and coking tests of coal at Denver, Colo., by A. W. Belden, G. R. Delamater, and J. W. Groves. 1909. 54 pp., 2 pls.

BULLETIN 373. The smokeless combustion of coal in boiler plants, by D. T. Randall and H. W. Weeks. 1909. 188 pp.

SURVEY PUBLICATIONS ON BRIQUETTING.

Besides the publications in the above list that deal specifically with briquetting, the following contain mention of processes, tests, etc.:

BULLETIN 261, pp. 134–168. Briquetting tests, by Joseph Hyde Pratt. 10 cents.

PROFESSIONAL PAPER 48, pt. 3, pp. 1389–1459. Briquetting tests, by Joseph Hyde Pratt. 50 cents.

BULLETIN 290, pp. 40–52. Briquetting tests, by J. A. Holmes. 20 cents.

BULLETIN 316, pp. 460–485. The condition of the briquetting industry in America, by E. W. Parker. 70 cents.

BULLETIN 332, pp. 36–46, et seq. Briquetting tests, by C. T. Malcolmson.

MINERAL RESOURCES, 1907, pp. 223–228. Coal briquetting in 1907, by E. W. Parker.

RECENT LITERATURE ON BRIQUETTING.

The following list of references to publications that have appeared within the last ten years is based on the partial bibliographies of briquetting in Bulletin 290 and Bulletin 363:

1899.

ATWATER, R. M. Domestic coke and briquettes from retort coke ovens. Iron Trade Review, January 26.

BINDER, O. Apparatus for testing pitch for briquette making. Colliery Guardian, June 16.

KOSMANN, ——. Welche Erfahrungen liegen über die Ofenfeuerung von Dampf-Kesseln und Brennofen mit Briketts vor? Mittheilungen des Deutschen Vereins für Fabrikation von Ziegeln u. s. w., Berlin, vol. 35, pp. 193–197.

Coal briquettes in Wales. U. S. Consular Reports, No. 327.

1900.

American coal briquets. Sci. Am., December 8.

BUHLER, ——. Fabrikation der Essigsäure und des Acetons, sowie von Briketts aus Hauskohlen. Zeitschrift für angewandte Chemie, p. 637.

Briquettes à hydrocarbures; procédé de Velna. Revue industrielle, Paris, vol. 31, pp. 298–299.

Briquettes as steam fuel. Iron and Coal Trade Review, December.

The manufacture of patent fuel in Wales. U. S. Consular Reports, No. 852.

1901.

ANDREP, ALEPH. Swedish methods of preparing peat fuel. Engineering News, vol. 45, p. 434.

BOCK, OTTO. Die Ziegelfabrikation, Leipzig.

CATLETT, C. Note on briquetting coking coals. Eng. and Min. Jour., vol. 71, p. 329.

FISCHER, Dr. F. Technologie der Brennstoffe, Braunschweig.

HEIDENSTAM, GUSTAF V. Manufacture of briquettes from wood waste. Engineer, London, vol. 92, p. 465.

Brikett Maschine, System Edison. Praktische Maschinen-Konstrukteur, vol. 34, p. 125.

Note on briquettes in Belgium. Eng. and Min. Jour., vol. 72, p. 850.

Note on briquette making in Germany. Eng. and Min. Jour., vol. 71, p. 593.

Untersuchungen von Torf-Briquettes. Dingler's Jour., Stuttgart, vol. 316, p. 225.

1902.

GRANVILLE, ——. Solidified crude-oil fuel. Railroad Gazette, New York, vol. 46, p. 958.

HEUMANN, ——. Erfahrungen mit der Verfeuerung von Torf-Briquettes. Deutsche landwirtschaftliche Presse, vol. 29, p. 247.

IRWIN, WM. G. Coal-briquetting industry in the United States. Iron Age, June 19.

KEGEL, C. Briquetting of brown coal. Glückauf, July 5.

KROUPA, GUSTAV. New process for preparing peat for briquetting and other purposes. Colliery Guardian, March 7.

MASON, F. H. Manufacture and use of briquettes in Germany. Eng. and Min. Jour., vol. 74, p. 244.

MIDDLETON, ——. Machinery for making briquettes. Engineer, vol. 77, p. 262.

SACHSE, ——. Peat fuel. Eng. Rec., vol. 46, p. 29.

SCHORR, ROBT. Briquetting and peat fuel. Eng. and Min. Jour., vol. 74, p. 714.
SCHORR, ROBT. The briquetting of fuels. Eng. and Min. Jour., vol. 74, p. 621.
STEGER, ——. Bindemittel für Brennstoffbriquetts. Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. 50, pp. 311–320.
WENDT, ——. Ore concentration, coal preparation, briquetting, etc. Glückauf, July 12.
Apparatus for compressing coal before coking. Genie civil, November 15.
German processes and machinery for briquette manufacture. U. S. Consular Reports, No. 1466, October 11.
Making peat briquettes by electric power. Eng. and Min. Jour., vol. 74, p. 41.
Manufacture of briquettes. Engineering, November 14.
Note on briquette plant in New Mexico. Eng. and Min. Jour., vol. 73, p. 313.
Utilization of peat as fuel. Eng. News, vol. 47, p. 476.
Verwendung von Braunkohlenbriquetts für Dampfkesselfeuerung, Halle. Zeitschrift für Heizungs-, Luftungs- und Wasserleitungstechnik, vol. 7, p. 49.

1903.

BJORLING, P. R. Briquettes and patent fuel. London, pp. 256.
BOOTH, W. H. Briquet fuel. Engineer, U. S. A., April 1, p. 251.
CARTER, W. E. H. Peat fuel, its manufacture and use. Ann. Rep. Ontario Bureau Mines.
GEHRE, ——. New process for making briquettes. Sci. Am. Suppl., vol. 55, p. 22871.
GIFFORD, R. L. Briquetting of flue dust, fine ore, and fuel. Eng. News, vol. 49, p. 140.
GIFFORD, R. L. Briquetting of fuel. Eng. News, vol. 49, pp. 235–236.
JUNEMANN, F. Die Briquette-Industrie und die Brennmaterialen, new ed., p. 320.
LOSE, ED. The briquette industry in France. Eng. and Min. Jour., vol. 76, pp. 277 and 431.
MASON, F. H. Lignite, peat, and coal-dust fuel in Germany. Elect. Rev., vol. 42, p. 612.
STEGER, ——. Die Herstellung kleinstückiger Briquetts. Stahl und Eisen, vol. 23, p. 1313.
VICKERS, ——. Lignite, peat, and coal-dust fuel. Sci. Am. Suppl., vol. 55, p. 22846.
Briketts. Gewerbeblatt aus Würtenberg, vol. 55, p. 361.
Briquettes as fuel in foreign countries. U. S. Consular Reports, vol. 26.
Desulfurit-Dauerbrand-Briketts der Gebr. Hopfner in Bleckendorf. Uhland's Technische Rundschau, Suppl., p. 101.
Fuel briquetting. Mines and Minerals, August.
Fuel-briquetting machinery. Engineer, U. S. A., vol. 40, p. 249.
Manufacture of peat fuel. Engineer, vol. 96, p. 500.
Versuche mit festem Petroleum als Heizstoff. Schiffbau, vol. 4, p. 517.
Zeitzer Eisengiesserei und Waschbau-A. G., Briquet-Fabrik. Praktische Maschinen-Konstrukteur, vol. 36, p. 203.

1904.

FULTON, JOHN. Fuel-briquetting industry. Mines and Minerals, vol. 25, p. 106.
GRADENWITZ, Alfred. Coal briquetting. Mining Reporter, December 29.
HOFBAUER, ——. Kohlenbriquetts aus ausgelaugter Weinhefe und Steinkohlenklein. Neueste Erfindungen und Erfahrungen, vol. 31, p. 248. See also vol. 31, pp. 33 and 310.
MASON, ——. Lignite, peat, and coal-dust fuel in Germany.
SCHÖNDELING, H. Aufbesserung der Steinkohlen Briquetts zwecks Rauchverminderung: Glückauf, November 5.

SCHORR, ROBERT. Fuel and mineral briquetting. Trans. Am. Inst. Min. Eng., vol. 35, p. 82.

SCHORR, ROBERT. The briquette plant at Stockton, Cal. Eng. and Min. Jour., vol. 78, p. 262.

WALSH, G. E. Briquetting fuel materials. Power, April.

WHITE and GRIFFIN. Machine pour la fabrication des briquettes de tourbe. Revue industrielle, vol. 35, p. 234.

WOODHEAD, HENRY. Briquetting of coal. Eng. and Min. Jour., vol. 78, p. 541.

Aglomeración de la hulla. Revista minera, metalúrgica y de ingeniería, vol. 55, p. 145.

Brikettfabrik. Braunkohle, vol. 3, pp. 225, 349.

Briquettfabrikation. Mittheilungen aus der Praxis des Dampfkesseln und Dampfmaschinen Betriebes, vol. 26, pp. 583–586.

1905.

CONSTAM, ——. Der Einfluss der Festigkeit von Steinkohlenbriquetts auf ihre Verdampfungsfähigkeit. Zeitschrift des Vereins deutscher Ingenieure, Berlin, vol. 48, pp. 973–975.

FULTON, JOHN. Coke, a treatise on the manufacture of coke and other prepared fuels and the saving of by-products. Scranton, Pa., pp. 406–462.

GERCKE, ——. Die Verwertung minderwertiger Brennstoffe insbesondere des Torfes. Zeitschrift des Vereins deutscher Ingenieure, May 27.

GRADENWITZ, ALFRED. Washing and briquetting plant. Mines and Minerals, September.

LOESER, ——. Verwendung von Braunkohlenbriquetts für Ringofenstreufeuer. Braunkohle Halle, vol. 3, pp. 33–36.

RANDAL, W. M. Briquette fuels. Power, March, p. 204.

SCHORR, ROBERT. Briquette press. Eng. and Min. Jour., October 7, p. 267.

WALSH, G. E. Briquetting fuel. Mining Reporter, April 13.

Manufacture of briquettes. Sci. Am. Suppl., July 1.

1906.

BARBER, C. M. Some notes on fuel briquetting in America. Sci. Am. Suppl., April 7.

KALLER, THEODOR. Artificial fuel. Sci. Am. Suppl., June 16.

MASHEK, J. G. Briquetting of fuels and minerals. Iron Age, April 19.

MUELLENHOFF, K. A. Briquetting of brown coal. Proc. Eng. Soc. Western Pennsylvania, May.

1907.

BLAUVELT, W. S. A brief record of progress in fuel briquetting at Detroit. Am. Gas Light Jour., September 23.

PARKER, E. W. Coal briquetting in the United States. Trans. Am. Inst. Min. Eng., pp. 581–620.

SAWARD, F. E. Southern coal for briquets. Manufacturers' Record, October 21.

THAU, A. Fortschritte im Kohlenstampfverfahren. Glückauf, July 27.

1908.

BOCK, F. Die Brikettierung der Steinkohlen. Glückauf, January 4.

COALES, H. G. Coalescine fuel from refuse. Eng. Digest, August, pp. 146–147.

FRANKENTHAL, L. J. Coal briquets: Their importation and use on Swiss railways. Monthly Consular Reports, April.

GERTNER, — —. Ueber Entstaubungsanlagen in Braunkohlen-Brikettfabriken. Zeit. Berg., Hüt. Sal.-Wesen, B. 56, H. 2, pp. B. 125–257.

D'INVILLIERS, R. Briquetted coal in Brooklyn. Eng. Rec., September 12.

LATHROP, L. A. Briquets made with tar, Shedlock process. Consular Reports, June.

MASHEK, J. G. Briquetting of fuels in British Columbia, Canada. Can. Min. Jour., January 15, February 1.

MASON, F. H. Briquets in Europe. Their use as locomotive fuel in France. Monthly Consular Reports, March.

MEEKER, CLIFFORD D. Briquetted coal in Brooklyn, N. Y. Eng. Rec., August 15, pp. 178–180.

NYSTROM, E. Peat and lignite: Manufacture and use in Europe. Ottawa, Canada, Dept. of Mines, pp. 130–170.

PARKER, E. W. The coal-briquet plant at Bankhead, Alberta. Trans. Am. Inst. Min. Eng., pp. 354–362, 389–393.

ROSENKRANS, MAX. Briquets from coal dust. Indust. World, April 27.

SCHOLZ, CARL. Coal briquetting. Eng. News, December 10, p. 642.

SCHORR, R. Lignite briquetting in Germany. Eng. and Min. Jour., February 29, pp. 460–461.

WADLEIGH, P. R. Coal briquets and their use in railroad, marine, and domestic service. Engineer, London, June 12.

Brikettierung. Verhütung der Staubbildung und Auftreiben der Pressformen. Zeit. Berg., Hüt. Sal.-Wesen, B. 56, H. 1, pp. 186–187.

New southern briquetting plant. Black Diamond, October 10, p. 16.

Tests of Russian coal and briquets. Colliery Guardian, November 22.

O

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 386

PLEISTOCENE GEOLOGY

OF THE

LEADVILLE QUADRANGLE, COLORADO

BY

STEPHEN R. CAPPS, JR.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

CONTENTS.

	Page.
Introduction	7
Part I. General Consideration of the Region	8
Topography	8
Glaciation	8
Evidences	8
Area glaciated	8
Elevation necessary to start glaciation	9
Glacial erosion	10
Cirques	10
Erosion of main valleys	11
Methods	12
Moraines	12
Striæ	14
Older drift	14
Possibilities of a still older glaciation	15
High terraces	15
General description	15
Age and origin	17
Interglacial epoch	20
Low terraces	21
Flats	22
Glacial changes in drainage	23
Eagle River valley	23
Arkansas Valley	24
East Fork of Arkansas Valley	24
Postglacial erosion	25
Part II. Special Consideration of Particular Areas	26
Roche Moutonnee Creek system	26
Rock Creek system	27
Homestake Creek system	28
Sources of the ice	28
Drift areas and moraines	32
Main valley	34
Older glaciation	36
Mitchell Glacier	36
Glacier east of Mitchell	38
Crane Park system	38
Sources of the ice	38
Older drift	40
Lake Fork system	40
Sources of the ice	41
Heavy-drift area	42
Moraines	43
High terraces	44
Low terraces	44

PART II. SPECIAL CONSIDERATION OF PARTICULAR AREAS—Continued. Page.
Cliff Glacier northwest of Soda Springs 45
Evergreen Lakes system 45
Sources of the ice 45
Heavy-drift area 47
Terminal moraine 48
System north of Half Moon Creek 48
Half Moon Creek system 49
Sources of the ice 49
Main valley 50
Moraines 51
Heavy drift and terraces 51
Older drift 52
High terraces 52
Low terraces 53
Cliff Glacier south of Half Moon Creek 54
Lake Creek system 54
Sources of the ice 54
Main valley 57
Heavy-drift area 57
Twin Lakes 58
Glacial erosion 59
Older drift 61
High terraces 62
Low terraces 63
Clear Creek system 64
East Fork Arkansas system 65
Sources of the ice 65
Main valley 67
Moraines 68
Amount of glacial erosion 69
High terraces 69
Low terraces 69
Upper Tenmile Creek system 69
Lower Tenmile Creek system 70
Sources of the ice 70
Heavy-drift area 72
Amount of glacial erosion 73
Recent gravels 74
West Fork Tenmile system 74
Wheeler Gulch 75
East side of Park Range 75
Sources of the ice 75
Older drift 76
Blue River system 77
Sources of the ice 77
Main valley and its moraines 79
Older drift 80
South Platte system 80
Sources of the ice 80
Main valley and its moraines 84
Glacial erosion 85
Older drift 85
High terraces 86

PART II. SPECIAL CONSIDERATION OF PARTICULAR AREAS—Continued. Page.
Cliff glaciers on Mounts Lincoln and Bross 86
Cameron amphitheater 86
Bross amphitheater 86
Horseshoe Gulch Glacier 87
Twelvemile Creek Glacier 88
South Fork Platte Glacier 89
Weston Gulch Glacier 89
Slumped area 90
Empire Gulch Glacier 90
Topography 90
Older drift 91
High terraces 92
Iowa Gulch Glacier 92
Topography 92
High terraces 92
Low terraces 93
Evans Gulch system 95
INDEX 97

ILLUSTRATIONS.

		Page.
PLATE I.	Map of the Leadville quadrangle, Colorado, showing Pleistocene geology	In pocket.
II.	*A*, Rock surface in cirque 1; *B*, Bowlders in heavy-drift area above Busk	40
III.	*A*, Lake Creek gorge and Monitor Rock; *B*, Truncated spur between Crystal Lake and Willis gulches	56
IV.	*A*, Head of Clinton Gulch; *B*, North lateral moraine of East Fork Arkansas system	68
V.	*A*, Cascades in Quandary Gulch; *B*, Bowlder-filled channel of Spruce Creek	78
VI.	*A*, View beyond end of Platte system, showing relations of high terraces to old and new moraines; *B*, Shallow draw on east side of South Platte River	84
VII.	*A*, Terminal moraine of Empire Gulch system; *B*, Upper Empire Gulch	90
VIII.	*A*, Little Evans Cirque; *B*, Postglacial cut in drift at mouth of Little Evans Gulch	94
FIGURE 1.	Cross section of Arkansas Valley near Granite	15
2.	High terraces south of Leadville	16
3.	Map to illustrate a glacial change of drainage in Eagle River Valley	23
4.	Cross section of Homestake Creek valley	35
5.	Diagram illustrating the relations of a glaciated valley and an unglaciated tributary	59
6.	Diagrammatic cross section of the trough of Lake Creek	60
7.	Longitudinal section of Crystal Lake Gulch and cross section of Lake Creek valley	61
8.	Same section as in figure 7, with different assumptions	61
9.	Sketch map of area between Lake and Cache creeks, showing relations of terraces to Mountain slope	63
10.	Section across divide between head of East Fork of the Arkansas and Mosquito Gulch	67
11.	Section south of terminal moraine of East Fork of the Arkansas	68
12.	Cross section of Tenmile Valley and an unglaciated hanging tributary	74
13.	Profile of Spruce Gulch	77
14.	Cross section of South Platte Valley between Mounts Lincoln and Silverheels	84
15.	Cross section of Empire Gulch above lower end of glacial system	91
16.	Cross section of Empire Gulch south of Long and Derry Hill	92
17.	Cross section of Iowa Gulch east of Arkansas River	93
18.	Cross section of Iowa Gulch	94

PLEISTOCENE GEOLOGY OF THE LEADVILLE QUADRANGLE, COLORADO.

By Stephen R. Capps, jr.

INTRODUCTION.

The field work on which this report is based was begun by the writer, in company with Mr. E. D. K. Leffingwell, in the summer of 1904. The work was undertaken privately, in connection with studies at the University of Chicago. During the following summer the writer, assisted by Messrs. C. A. Kirtley and J. M. Hill, continued the work, to which some support was given by the United States Geological Survey. The investigation was carried on under the advice and direct supervision of Prof. R. D. Salisbury, to whom acknowledgments are due for many valuable suggestions and criticisms.

This region was chosen for the study of glaciation because it was believed to be a type for the mountains of Colorado. In the reports of the Hayden Survey [a] some of the morainic areas west of Arkansas River were mapped, and in his Leadville monograph Mr. S. F. Emmons [b] mentioned briefly the effects of glaciation in this area. Prof. L. G. Westgate [c] and W. M. Davis [d] also recently published articles on the glaciation in a part of the Lake Creek valley, but aside from these publications very little attention appears to have been given to the Pleistocene geology of this region.

[a] Ann. Rept. U. S. Geog. and Geol. Surv. Terr. for 1873, pp. 51–53; idem for 1874, pp. 48–50.

[b] Mon. U. S. Geol. Survey, vol. 12, 1886, pp. 41–42.

[c] Jour. Geol., vol. 13, 1905, pp. 285–312.

[d] Bull. Mus. Comp. Zool., vol. 49 (Geol. series, vol. 8, No. 1), 1905, pp. 1–11; Appalachia, vol. 10 (No. 4), 1904, pp. 392–404.

PART I.

GENERAL CONSIDERATION OF THE REGION.

TOPOGRAPHY.

The chief topographic features of this region are the two great parallel north-south mountain ranges, the Sawatch on the west and the Park on the east. The peaks of both rise to heights of more than 14,000 feet. In the trough between these ranges lie Arkansas and Eagle rivers, the former flowing south and the latter north from Tennessee Pass. East Fork Arkansas River heads in the Park Range to the northeast, southeast of Fremont Pass, and from this pass Tenmile Creek flows north. East of the crest of the Park Range Blue River drains the area north of the Continental Divide, and the South Platte the remainder of the slope.

GLACIATION.

EVIDENCES OF GLACIATION.

Within this quadrangle, which has an area of 945 square miles, more than 350 square miles show definitely the effects of glaciation, and it is certain that at its maximum extent the ice covered a somewhat larger area. The former domination by glaciers of all the important mountain valleys of the region is indicated by a number of characteristic and unmistakable phenomena: (1) Many valleys have U-shaped cross sections, truncated lateral rock spurs, and more or less cliff-like head and side walls. (2) The bed rock in these valleys is often polished and striated, and many of the lakes occupy rock basins. (3) The valleys usually contain definite lateral and terminal moraines, with characteristic topography and constitution. (4) There are numerous departures from the normal relations of stream-developed valleys, as shown by (1) the topographic unconformities of the tributaries, (2) the incomplete drainage control, both of the upper parts of the valleys and of the moraine deposits, and (3) the freedom of the upper parts of the valleys from the products of weathering.

AREA GLACIATED.

Although little more than two-fifths of the area of this quadrangle shows the effects of glaciation, the ice of the last epoch covered by far the greater part of the surface of the mountains in the higher

parts of both great ranges. Here only the narrow crests of the ridges projected above the ice. From this collecting field of snow and ice, which was essentially continuous along the crests of the ranges, the glacial ice moved down the mountains. The ice was deepest and most vigorous in the important mountain valleys, each of which was occupied by a glacier, and ice tongues extended far down the mountain slopes, many of them out onto the piedmont plain below. Some of the glaciers consisted of a single lobe, without lateral feeders; others, more favorably situated, were fed by numerous heads, and it was these many-headed glaciers which reached the greatest size and which most profoundly altered the shape of their valleys. Within this quadrangle there were 26 glaciers, or systems of glaciers, of some importance, besides 11 glaciers of smaller size, making 37 in all (Pl. I). These glaciers were distributed as follows:

Glaciers that formerly occupied the Leadville quadrangle.

	Length in miles.	Area in square miles.	Range of elevation in feet.
In valley of Roche Moutonnée Creek	12	7	13,000 to 9,000
In valley of Rock Creek	7	6	13,000 to 9,500
In valley of Homestake Creek	17	46	13,000 to 8,800
East of Mitchell	2	2	11,000 to 9,500
West of Mitchell	4	5	12,000 to 10,000
West of Crane Park	6	20	13,000 to 10,000
In valley of Lake Fork	10	23	12,500 to 9,700
In valleys northeast of Mount Massive	6	15	13,600 to 9,700
In valley of Half Moon Creek	9	18	13,500 to 9,600
In valley of Lake Creek	20	56	13,300 to 9,100
In valley of Clear Creek	18	12	13,000 to 8,900
Between Half Moon Creek and Evergreen Lakes systems	2	3	12,500 to 10,400
Three small cliff glaciers in Sawatch Range		1½	
In Weston Gulch	4	4	13,100 to 9,900
In Empire Gulch	4	3	13,200 to 10,100
In Iowa Gulch	7	6	13,300 to 9,900
In Evans Gulch	6	6	13,000 to 10,300
In valley of East Fork of the Arkansas	15	20	13,000 to 9,900
In valley of Tenmile Creek	10	12	13,000 to 9,800
In valley of West Fork of Tenmile Creek	6	5	12,000 to 9,700
In valley No. 1, northwest of Breckenridge	2	1	12,000 to 9,700
In valley No. 3, southwest of Breckenridge	3	1	12,000 to 9,700
In valley of Blue River	12	14	13,000 to 9,700
In valley of South Platte River	16	49	13,700 to 9,900
In valley of Fourmile Creek	9	11	13,000 to 9,900
In valley of Twelvemile Creek	7	6	13,000 to 9,800
In valley of South Fork of South Platte River	5	3	12,000 to 10,300
Five small cliff glaciers in Park Range		2½	
Total area glaciated		358	

ELEVATION NECESSARY TO START GLACIATION.

On the east slope of the Sawatch Range the minimum elevation at which glaciers started was about 12,000 feet. A few valleys which headed at elevations of 13,000 feet or more were unglaciated, but in most places an elevation of 12,000 feet was sufficient for the formation of glacial ice, and the heads of the glaciers range from this elevation to 13,600 feet. The west slope of the Sawatch Range is beyond the limits of the Leadville quadrangle and was not studied in detail.

Although the west slope shows the effects of glaciation of the same order of intensity as that on the east slope, the data at hand are so few that it is impossible to make accurate comparisons with the east slope in respect to the area which the ice covered or the elevation which was necessary to start glaciation.

In the higher parts of the Park Range many of the peaks reach elevations of nearly 14,000 feet, and below these peaks on both the east and the west slopes of the range all the larger valleys were occupied by glaciers that headed at elevations of 13,000 feet or more. Those on the east slope, however, were larger and more vigorous and occupied three-fifths of the total glaciated area of this range. On this slope, too, the height necessary to start glaciation was in some places only 12,000 feet, while in most valleys on the west slope a height of considerably more than 12,000 feet was necessary. It is probable that the greater size of the glaciers on the east side of the range was due to the superior size of the preglacial valleys here, rather than to any advantage of exposure or precipitation.

The area and length of any glacier depended on the following factors: (1) The height of the mountain ridges surrounding it, (2) the shape and area of the catchment basins, (3) the number and size of the lateral valleys which contributed ice to it, (4) the slope and shape of the valley floor, (5) the exposure, and (6) the precipitation. In the Sawatch Range the Lake Creek and Homestake glaciers were most favored in these particulars, while in the Park Range the South Platte Glacier had the most advantageous position.

Hayden[a] suggested that there was once a great glacier in the valley of the Arkansas, fed by the tributary valleys from both ranges, but evidence of such a glacier is altogether lacking.

GLACIAL EROSION.

A comparison of the topography of a mountain region which has been subjected to severe glaciation with that of a similar region which has not been glaciated shows readily that valleys which have contained glaciers of any considerable size have developed certain distinct features that are lacking in unglaciated regions.

Cirques.—The most striking of these features are the glacial cirques, illustrated in this quadrangle by the head of almost every valley that reaches back to the higher parts of either great mountain range. Normally these cirques have steep walls at the head and sides of the upper valley and present in cross section a marked U shape, in contrast to the V shape common to most unglaciated valleys in the high mountains. This U shape is the result of the widening and deepening of the valley by glacial erosion, and in many places the cutting back

[a] Ann. Rept. U. S. Geog. and Geol. Surv. Terr. for 1873, p. 48.

of the head walls and dividing ridges has left only a row of serrate peaks between adjoining cirques. The glacial deepening of the valley is perhaps greatest near its head, and this increases the gradient of the stream at its upper end and reduces it below.

The abrasive action of the ice is shown in many places by the smoothing and striations of the valley walls and floors, and it is certain that most of the cirques, as left by the ice, contained very little loose material. As soon as the glaciers retreated, however, these steep, bare cliffs were attacked by the agencies of weathering, and great heaps of postglacial talus now lie at the base of many of the steep slopes. The bottoms of many of the cirques show bare bed rock, and some of the hollows gouged in this rock by the ice contain lakes.

Many of the valleys in this quadrangle, although showing definite evidences of glaciation, have failed to develop the typical steep-walled cirque. This may be due to the feebleness of the glaciers in them, for many of the valleys contained only small glaciers, or to the original shapes of the valleys. Thus the two small glaciers between Lake and Clear creeks failed to excavate their valleys sufficiently to form cirques because their erosive action was necessarily weak. The two heads of Mosquito Gulch and the head of Sacramento Gulch, all of the South Platte system, although they lie in the highest part of the Park Range and contained strong glaciers, were not deeply eroded by the ice and developed no cliffs at their heads. Here, however, the lack of cirque development was due to the broad, flat character of the valley heads; the ice was spread out in a comparatively thin lobe and the glacial deepening was slight.

Erosion of main valleys.—Each of the larger systems of glaciers was formed by the junction of a number of cirques, creating a single large lobe which extended down the main valley. In most of these trunk valleys there is an area, below the head of the cirque and above the morainic deposits, in which the ice has widened and deepened the valley. This widening and deepening commonly results in the development of a U-shaped cross section.

In the normal development of a stream-cut valley and its tributaries the constant tendency of each tributary is to keep its bed cut down to topographic conformity with the main valley. The bed of a glacier is filled to a considerable depth by the ice, and while the floor of the main valley is sustaining glacial erosion the ice in the tributary valley, if the tributary has a glacier, is prevented by the great depth of the ice in the trunk valley from lowering its bottom correspondingly. When the ice retreats the topographic unconformity thus produced is revealed. Some idea of the amount of the glacial deepening of the main valley may be gained by noting the amount of this topographic unconformity. Estimates based on the height

of the mouth of a hanging tributary were made for a number of gulches. The estimated deepening at some of these places is less than the maximum deepening in other parts of the same valley. Such estimates are subject to error because (*a*) it is impossible to reconstruct accurately the preglacial profile of the tributary stream; (*b*) it is possible that the preglacial tributary did not join the main stream with topographic conformity; (*c*) the preglacial valley may have been U-shaped and not V-shaped (this would make the estimates too small); (*d*) the calculations are based on field sketches and aneroid measurements, both of which are subject to error. Estimates were made of the following valleys:

Estimates of glacial deepening of trunk valleys at junctions of tributary valleys.

	Feet.
Homestake Valley	400
Lake Creek valley	800
Empire Gulch valley	400
Tenmile Valley	200
South Platte Valley	300

Besides this glacial deepening, the widening of the valley by the erosion of the ice is important, so that in many valleys the material removed by the ice was very great.

Methods of glacial erosion.—In considering the removal by the glaciers of this great mass of material two distinct methods of erosion are worthy of attention—plucking and rasping. These methods vary in importance in different regions, according to the characteristics of the bed rock. In an area where the rock is broken by numerous joints, plucking is by far the more important method. Under the enormous pressure of the ice above, that part of the glacier which rests upon the bed rock closes around any inequality of the rock surface and plucks out blocks from the down-valley side of any irregularity of its bed. In this way many of the projections of rock in a glaciated valley have been smoothed on the stoss side and made angular or subangular on the lee side.

In regions where the bed rock is compact and little jointed the ice accomplishes most of its erosion by rasping. The action of the glacier, shod on its underside with fragments of rock, has been likened to that of a huge flexible file, exactly fitting every projection and depression of its bed. By the constant rasping of the rock by the bottom of the glacier, irregularities of the rock surface are removed, and the tendency is toward the development of a perfectly smooth U-shaped trough.

MORAINES.

In the widening and deepening of the glaciated valleys great quantities of fragmental material were taken up by the ice and later de-

posited toward the lower ends of the glaciers as moraines. The glacial drift of which these moraines are formed is characteristic in that it is composed of an unassorted mixture of fine and coarse materials. Bowlders many feet in diameter lie embedded in fine clay. Some of the bowlders are rounded, but many are angular or subangular, and some of them bear striæ. The bowlders were derived from a great variety of rocks; in fact, every kind of rock over which a glacier passed is represented in the bowlders of its moraines.

The moraines form conspicuous topographic features in many of the valleys of this quadrangle. Some of the glaciers, such as those in the valleys of Homestake, Tenmile, and Weston creeks, ended in narrow, steep-walled gulches, and in these places the materials dropped by the ice were carried away by streams, perhaps as rapidly as they were deposited. Other glaciers, such as those of the Lake Fork and Lake Creek valleys, advanced beyond the foot of the mountains onto the plain beyond, and here the conditions for the building of moraines were most favorable.

The moraine deposits may be divided into three classes, which have characteristic forms but which grade into one another. These are (1) lateral moraines, (2) terminal moraines, and (3) ground moraines.

(1) Lateral moraines occur as benches of drift lying against the rock valley wall or as great ridges composed wholly of drift, one on either side of the lower end of the glaciated area. Some of these ridges extend for several miles below the base of the mountains, and slope with even, gradually descending crests toward the terminal moraine. In the Clear Creek valley the crests of the lateral moraines are, at their maximum heights, 700 feet above the valley bottom. Toward their lower ends the lateral moraines usually converge and merge into the terminal-moraine deposits.

(2) At the lower end of an area that was occupied by a glacier there is generally a body of drift which has extremely irregular topography. This is the terminal moraine. Its surface is characteristically composed of an irregular succession of hummocks and hollows, many of the hollows being occupied by ponds or lakes. Bowlders, large and small, lie scattered over the surface, which may show no signs of drainage control. Terminal moraines are composed largely of unassorted drift, but some sections show a rude tendency toward stratification, with irregular lenses of sand or gravel. The best examples of terminal moraines in this quadrangle occur at the lower ends of the Crane Park, Lake Fork, and Blue River systems.

(3) In almost every glaciated valley, above the terminal moraine, there is an area in which a considerable amount of drift material occurs in the valley bottom. Wherever this drift is sufficiently thick to conceal the topography of the underlying rock it is mapped as

"heavy drift." Some of this was doubtless deposited by the ice during its retreat, but much of it was deposited beneath the body of the ice as ground moraine. It is at many places impossible to distinguish this ground moraine from the drift deposited as ground moraine by the retreating ice, and no distinction between these has been made on the accompanying map (Pl. I).

STRIÆ.

The results of the rasping of their beds by the glaciers are still to be seen in places, as polished surfaces of rock, striæ, and groovings. These polished surfaces and striæ have commonly been obliterated by postglacial weathering, but occasionally they have been preserved, and those that remain point down valley in the direction of the ice movement.

OLDER DRIFT.

At a number of places in this quadrangle there are areas of scattered bowlders, or bodies of unstratified drift, which are certainly of glacial origin, but which are noticeably different from the deposits of the last glaciers. That they are of glacial origin is evinced by their lack of stratification, by the angular or subangular shape of many of the bowlders, a few of which bear striæ, and by their constitution, which shows that they were not assembled by the agency of water. Bowlders many feet in diameter are intermingled with finer bits of rock and with sands and clays.

Wherever found this older drift lies just outside of the moraines of the last epoch, at many places in direct contact with them. That it is much older than the deposits of the last glaciers is shown by the decayed condition of the bowlders. Many of these are so rotten that they crumble readily under the hammer. Others have so weathered that the more resistant crystals stand out roughly from the surface. Only the more resistant quartzite bowlders remain fresh and firm. This drift shows the effects of long oxidation. In cuts it is seen to be oxidized and yellow to a depth of many feet, while the last drift is at many places blue and unoxidized to the surface.

The topographic position of this older drift and its evidently great age indicate that there was an epoch of glaciation in this region considerably earlier than the last. In this earlier epoch the ice occupied approximately the same area as did the ice of the last epoch. Where the glaciers extended farther down valley than those of the last epoch, there are in places remnants of the older moraines. Doubtless, in many other valleys the last ice advanced over these older moraines and either removed them or covered them with newer drift. The meager traces of older drift which still remain occur only where the older glaciers had a greater extent than their successors and where

erosion has not removed the deposits of the early ice. A further conclusive bit of evidence as to the relations of the two drift bodies came to light during the summer of 1906, when the placer diggings in the Snowstorm mine, in the moraines of the Platte system, southeast of London Junction, showed a body of older, decayed drift overlain by younger, fresh drift.

POSSIBILITY OF A STILL EARLIER GLACIATION.

Two miles above Granite, on the east side of Arkansas River (fig. 1), bowlders that came from the Sawatch Mountains were found 200 feet above the river. These bowlders are few and are much weathered, though composed of resistant rock—a distinctive porphyritic granite characteristic of the range west of the Twin Lakes and the Clear Creek region. Their position beyond the limits of the ice of both well-determined epochs of glaciation points to a possible glacial epoch older than either, the drift of which has been entirely removed.

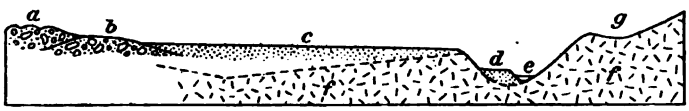


FIGURE 1.—Generalized section across the valley of the Arkansas, to illustrate the conditions in the vicinity of Granite. *a*, Terminal moraine of last epoch from a side valley; *b*, moraine of older drift; *c*, high terrace lying against older drift; *d*, low terrace corresponding in age to *a*; *e*, Arkansas River; *f*, granite in which river cut a channel after older glacial epoch; *g*, bowlders from mountains on opposite side of old valley, which appear to be older than *b*. Broken line indicates the probable preglacial valley of Arkansas River. Horizontal and vertical scale, 1 inch=one-fourth mile.

Another hypothesis might account for the position of these bowlders. During the excavation of the Arkansas Valley the axis of the two slopes might at some time have been farther east than it is now, and the bowlders might have been deposited at that time. This hypothesis seems far less probable, however, than that of the glacial origin of these bowlders, for in the great interval of time which would be necessary for the river to develop a valley 200 feet below these bowlders they would probably have had time to decompose.

HIGH TERRACES.

GENERAL DESCRIPTION.

A striking topographic feature of this region is the great number of high terraces in the Arkansas Valley. These are seen at their best on the east side of the river, between East Fork, Arkansas River, and Weston Gulch (fig. 2), but they extend both north and south of these limits, as well as to the base of the Sawatch Mountains.

Considered as a unit, it appears that these terraces, although now ut into by Arkansas River and its tributaries, are the remnants f two great, gently inclined piedmont plains, which extend con- nuously along the base of the two great mountain ranges and sloped own to join at the valley bottom. Arkansas River had its course at e junction of the two slopes.

Between the gulches in the terraces there are uneroded, flat-topped idges, or mesas, which show the original slope of the plain away from e mountains. This slope ranges from 3½° at the mountain base to ½° at the river edge. Along Arkansas River the flat tops of the ter- ices slope down the valley toward the south, parallel to the base of e mountains, at a rate of a little more than 1°. There are local ariations in this slope, however, which are seen best at the mouths f the gulches from which the gravels came. Here the slope is not at of an inclined plain, but of a flat fan, the apex being at the outh of the gulch, from which the surface declines toward the eriphery of the fan.

FIGURE 2.—High terraces south of Leadville.

The materials that form the high terraces can be seen in numerous cuts and prospect holes, and they have a characteristic appearance wherever exposed. They consist of imperfectly stratified gravels, with an occasional lens of sand. The gravels are uniformly coarser toward the mountains and finer toward the river; but even in the axis of the valley the pebbles composing them average several inches in diameter, and the deposits include no laminated clays such as are laid down in bodies of standing water. In Little Union Gulch, near Arkansas River, the gravels have been cemented into a loose conglomerate by calcium carbonate.

The surface configuration, the topographic relations, and the structure of the terraces seem to show conclusively that their materials were laid down as alluvial-fan and alluvial-plain deposits,[a] and that these separate alluvial fans laid down by Arkansas River and its tributaries grew until a great compound alluvial fan was formed along the base of each of the great mountain ranges. The lack of

[a] So far as is known to the writer the reference of these gravels to fluvio-glacial deposition was first made in an article published in 1904. Capps, S. R., and Leffingwell, E. D. K., Jour. Geology, vol. 12, 1904, pp. 702–705.

distinct, continuous beds of stratification is characteristic of the deposits of fan-building streams, with their frequent changes of channel, as is also the gradation from coarse materials at the mountain base to finer toward the valley axis, though by no means fine even at the lower edges of the terraces.

AGE AND ORIGIN OF HIGH TERRACES.

The physical condition and the topography of the gravels show them to be of considerable age. Cuts and shafts 60 to 80 feet deep show that the terrace materials are completely oxidized to the bottom. Bowlders of rather resistant rock, which must have been hard and firm when they were shaped and deposited, are now deeply decayed. Only the quartzite bowlders are still fresh and firm. The gravels also show age by the erosion which they have suffered. Great gulches have been cut into them. Iowa Gulch, the deepest of these, cuts 500 feet into these gravels without reaching bed rock. In almost every place where moraines of the older epoch of glaciation occur the high-terrace gravels appear just beyond them. In many places there is only a slight topographic break between the two, and in the amount of oxidization, in the decayed condition of the materials, and in the stage of erosion of the surface, these gravels agree well with the older glacial drift. The upper part of them, at least, was probably deposited during the older glacial period.

But there is positive proof, aside from the topographic relations and the condition of decay, that the older drift and the high terraces belong to about the same period. One mile north of Leadville a shaft through the gravels showed new drift overlying the high-terrace gravels. Two miles west of Leadville a prospect hole showed glacial drift of the older epoch overlain by high-terrace gravels. Thus we see that the high-terrace gravels were deposited before the last glacial epoch, and some of them after the maximum advance of the ice of the older epoch of glaciation. It is probable that these gravels which overlie the older drift were laid down during or soon after the retreat of the older glaciers, for the cutting of the interglacial gorges in the terraces would have soon made impossible the deposition by streams of any considerable amount of materials on their tops.

In addition to the typical development of these gravels in the Arkansas Valley, there are similar gravels on the east side of the Park Range. These lie beyond the moraines of the Platte system of glaciers, and bear the same topographic and structural relations to the older drift of this system as do the Arkansas terraces to the older moraines with which they are associated. The gravels in the Platte Valley, however, did not suffer so much interglacial erosion and do not show the striking terraced appearance exhibited by those in the

valley of the Arkansas. The gravels in the Platte Valley were doubtless deposited at the same time and under the same conditions as those in the Arkansas Valley.

The physical and topographic relations of the high-terrace gravels indicate that the conditions of their deposition were as follows: The older glaciers advanced down the stream-developed valleys, where the rock was deeply weathered and there was abundant talus. Under these conditions the ice was heavily loaded with débris. To the extraglacial streams, swollen by the melting snow and ice, abundant material was supplied by the glaciers and by accelerated stream cutting in the unglaciated valleys. These streams were normally retarded by the lessened gradient at the mouths of the gorges, and consequently dropped their excess load in the order of the size of the material. This tendency of the streams to deposit their loads was stimulated by the partial obstruction of the Arkansas Valley by the glaciers from the Sawatch Mountains. Possibly lakes were formed, but if formed they were shallow and only temporary, for they would have been rapidly filled by the influx of materials from the loaded streams. They could not have been deep enough for the deposition of the terraces because the glaciers from the Lake and Clear Creek valleys never obstructed the Arkansas Valley to any great height. This aggradation of the Arkansas Valley by the alluvial deposits of the river and its tributaries continued until the end of the older glacial epoch.

The high-terrace deposits of the Arkansas Valley have been described by Hayden,[a] Emmons,[b] and others as lacustrine deposits, laid down in a glacial period during which the ice from the valleys of Lake Creek, Clear Creek, and other tributaries blocked the valley of the Arkansas, thus forming a lake above these ice obstructions. The present slopes of the terrace surface are referred to tilting subsequent to the deposition of the gravels.

There are a number of objections to this hypothesis:

(1) The elevation to which the ice from its tributary valleys dammed Arkansas River, as shown by the moraines, is nowhere above 9,400 feet, while above Leadville the high-terrace gravels reach an elevation of more than 11,000 feet. Thus the glacial obstruction of the Arkansas was entirely inadequate to form a lake large enough to permit the deposition of these gravels.

(2) If such a lake had existed there would probably have been beach lines, shore terraces, deltas, and other shore features which would still be recognizable, but no trace of any of these features was observed. If these were lake beds the outer edge of the gravels would

[a] Ann. Rept. U. S. Geog. and Geol. Surv. Terr. for 1873, p. 53; idem for 1874, p. 52.
[b] Mon. U. S. Geol. Survey, vol. 12, 1886, pp. 41, 71, 72.

naturally be the shore line of the lake, yet the upper edge of the gravel ranges in elevation from 9,100 to 11,000 feet, and rises at the mouth of the tributary valleys.

(3) As appears from their structure seen in many surface exposures these gravels differ essentially from lake deposits: (*a*) They include no continuous stratified beds, and in places coarse gravels and sand are intermingled. (*b*) All delta structures are wanting. (*c*) There are coarse gravels at points that would have been near the center of the hypothetical lake, and fine laminated clays, such as would have been deposited in the offshore portions of such a lake, are absent.

(4) Emmons[a] argues that the present slopes of the terraces are due to tilting subsequent to their deposition. There is evidence that the upper edges of the terrace gravels have in places been faulted upward to some extent since their deposition, and such uplifts doubtless account for some isolated patches of the terrace material that occur well up on the slopes of the mountain range. Such an uplift, however, could scarcely account for the slopes of the terrace below the base of the mountains. It seems improbable (*a*) that tilting should have occurred in the gravels on both sides of the valley, with the axis of tilting at the valley axis and the tilting essentially equal on both sides; (*b*) that all of the terraces should have had the normal river valley slope of about 1° to the south; and (*c*) that the component parts of the terraces should have the slopes of a normal alluvial fan.

(5) It is an open question whether the advance of the glaciers from the tributary valleys across the Arkansas Valley would not have been so slow that the débris-loaded Arkansas River would have had time to keep its floor graded up to the level of the outlet beyond the end of the glacier. If this advance was slow enough no lake would have been formed.[b]

---

[a] Op. cit.

[b] Since the above was written Emmons and Irving have published, in Bulletin 320 of the Geological Survey (The Downtown district of Leadville), more details concerning the material of these terraces. It appears that, although not insisting that a permanent lake filled this part of the Arkansas Valley, Emmons contends that the evidence disclosed by many shafts sunk on the high terraces near Leadville points to the temporary ponding back of considerable bodies of water by the damming up of the Arkansas Valley near Granite during the earlier glacial epoch These shafts, after traversing 100 feet or more of coarse gravel or bowlder wash, pass into fine-grained marly silts, clays, and sands, which the miners call "lake beds" on account of their stratified appearance. They carry sporadically large angular rock masses which would appear to have been dropped from floating ice. Many of the sand beds, alternating with clays, yield strong flows of water when pierced. These characteristics, and the fact that within large areas these fine-grained materials have been found whenever the overlying gravel or wash has been passed through, indicate, Emmons argues, deposition in still rather than in running water.

He states that mine workings disclose movement or fault planes traversing these so-called lake beds, which afford definite proof of considerable elevation of the Mosquito Range back of Leadville since glacial time.

Although the topography and the oxidation and decay of the high-terrace gravels correspond closely with those of the older drift, it is possible that the enormous amount of material included in these terraces is too great to be referred to a single glacial epoch. Numerous mining shafts show that the gravels have a thickness of 300 to 600 feet over most of the area in which they occur. As far as was observed, the gravels are completely oxidized to their base. This suggests that the materials were deposited slowly and were oxidized as deposited rather than that they were deposited rapidly in a cool climate. If they were laid down during a glacial epoch rapid deposition would have been necessary for the accumulation of beds 500 feet thick.

An uplift of the two mountain ranges in preglacial times might have rejuvenated the streams and given them a transporting power in their upper courses which they did not have below the base of the mountains. This uplift might have marked the beginning of a period of alluvial fan and plain building which culminated at the time of the older glacial epoch. The present relations of the older drift and the high terraces would have been the same in either course of events. If the glacial deepening of the valleys during the older epoch lowered them to any great extent, the gradient of the streams might have been reduced to that which they had before their rejuvenation, and on the retreat of the ice they would have been able to cut their interglacial gorges into their former plain of aggradation. If the terraces are the result of deposition in both preglacial and early glacial times, both mountain ranges must have been uplifted at about the same time, and in both the fan building ended soon after the older epoch.

INTERGLACIAL EPOCH.

As the ice of the earlier epoch retreated the glaciated valleys were subjected to a very different set of conditions. The uncovered rock surfaces were subjected to the agencies of weathering. Stream erosion played an important part, and the irregular topography of the moraine-covered areas was gradually brought under erosional control. The streams, which in glacial times were loaded to their full capacity, were no longer supplied with such an abundance of materials, and were able to intrench themselves in their own alluvial deposits. Below Leadville these interglacial gorges are cut more than 500 feet into the older glacial valley trains. South of Granite Gulch, Arkansas River, which was forced by the older glaciers onto the rock slope of its east valley wall, was continually cutting its gorge deeper, and by the end of interglacial times had cut a gorge 400 feet deep into the crystalline rock.

All the evidence at hand leads to the conclusion that the time which elapsed between the two epochs of glaciation was very long—much longer than the time which has elapsed since the last epoch. A comparison of the materials of the last moraines strengthens this impression. The materials of the older drift are invariably deeply oxidized, and all but the more resistant bowlders are falling to pieces. The drift of the last glaciers, on the contrary, are rarely oxidized more than a few inches below the surface, and the bowlders appear as fresh and sound as though they had been deposited yesterday. Many times the present amount of weathering will be necessary before the last moraines are as old in appearance as the older moraines now are.

LOW TERRACES.

As compared with the high terraces the low terraces are very inconspicuous topographic features. They exist only in the bottoms of the gorges or flats which were eroded in the high-terrace gravels in interglacial times. Most of them occur just below the imposing high terraces, many of which rise 200 to 300 feet above the low-terrace level. Few of the low-terrace tops are more than 30 feet above the stream. The relations of these gravels to the moraines of the last glaciers are the same as those of the high terraces to the older drift (p. 17). Like the new drift, the gravels are unoxidized and undecayed, and the erosion which they have suffered is due to cutting by large streams rather than to the gradual growth of gullies back into the terrace plain.

These terraces are composed of unstratified or partly stratified gravels, which include here and there lenses of sand and show no continuous bedding planes. The gravels are in general coarser nearer their source and finer downstream. They consist of a great variety of materials, most of which can be traced to the mountains upstream. The terrace plain has a slope which ranges from 3½° to 1½°, depending on the distance from the source of the materials. In structure, in materials, and in slope the low-terrace gravels are very similar to the high-terrace gravels; they differ only in age and in topographic development; yet, because of their evident position in bottoms of the gulches and in the valley flats, no one has thought of calling them lake-bed deposits, as the high-terrace gravels have been called.

The conditions for the deposition of the low-terrace gravels were as follows: In interglacial times the great gorges and valley flats were cut into the high-terrace gravels. Down these gulches the last glaciers advanced, bringing to their ends large amounts of débris and there supplying it to the streams, swollen by the melting ice. These overloaded streams began to deposit and built up valley trains for many miles downstream. This deposition continued for some

time after the retreat of the ice began, as is evinced by the low-terrace gravels within the glaciated area of the East Fork of the Arkansas.

Comparing the low terraces with the high terraces, we observe a close similarity in lithological contents, but a great difference in age. Most notable, however, is the vast difference in the amount of material, the low terraces containing, even at their maximum extension, a comparatively small amount. The difference is even more striking when we consider that the extent of the glaciation in the periods when the two sets of terraces were formed was approximately the same.

The failure of the last glacial streams to build great terraces is referable to two sets of facts: First, the ice of the older epoch of glaciation advanced down valleys which were stream cut and had the V shape of such valleys. The walls of these valleys were doubtless deeply weathered, so that the ice had great quantities of loose material to handle. Although there was a considerable period of weathering between the two glacial epochs, the fresh rock surfaces left by the older ice do not seem to have been weathered to a great depth, and therefore the last ice had comparatively little loose material at hand. Secondly, the streams from the older ice flowed from their glaciers into a broad flat, in which the gradient of the stream was decreased by the Clear Creek and Lake Creek glaciers damming up the valley, so that conditions were ideal for the streams to drop their load. On the other hand, the streams from the last glaciers flowed into the deep, canyon-like gulches cut into the high terraces. In these narrow valleys the glacial waters were concentrated and held much of their load, while the glaciers below failed to dam Arkansas River effectually, so the materials were carried away by the streams almost as fast as the glaciers supplied them.

In the narrow valleys in which the low terraces were deposited the active streams have been cutting steadily since the end of the last ice advance, and a great part of the low-terrace gravels have been removed.

FLATS.

Along Arkansas and Eagle rivers there are a number of flats of considerable area which owe their existence to the effect that glaciation had upon the drainage.

In the valley of the Eagle there is a flat extending from Pando upstream for about 3 miles. This flat, as represented on the topographic map, appears to have a considerable slope, but a rather accurate level shows that its slope is not more than 20 or 30 feet in the 3 miles. This flat was formed by the damming of Eagle River by the ice from the Homestake Creek Glacier. It is not evident that any considerable lake ever occupied this flat, as no shore lines were observed above Pando, but the lessening of the gradient of the river, by decreasing its carrying capacity, would have been sufficient to

cause the building up of the flat. On the south side of the main moraine ridge, north of Pando, there are what appear to be shore lines, indicating that a small lake existed between this moraine ridge and the smaller one south of Pando.

Crane Park was formed because the ice of the Crane Park Glacier pushed out and retarded Tennessee Fork above its moraines. Another considerable flat occurs above the point where the moraines of the Lake Fork Glacier pushed across to the terraces on the east side of the river. No definite shore lines occur here to show whether or not a lake ever occupied this flat, but if there ever was a lake here it could never have stood much higher than the present flat level, for the ice advanced scarcely far enough to dam the valley at all.

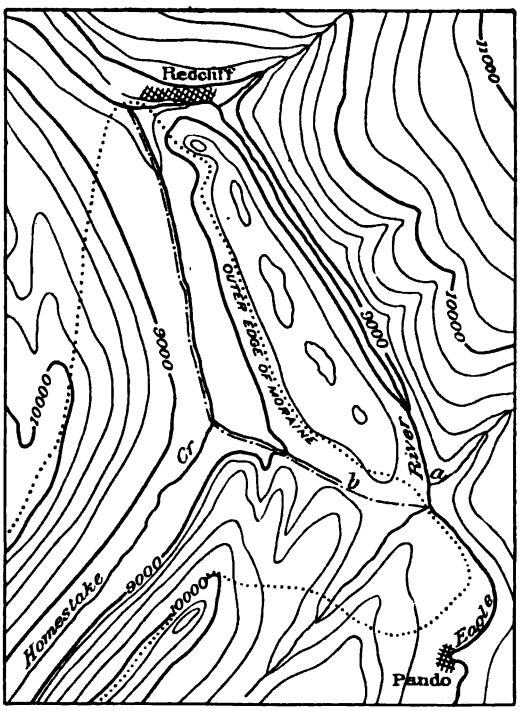


FIGURE 3.—Sketch map to illustrate a glacial change of drainage in Eagle River valley. The map comprises an area of about 17 square miles near Pando; *a* represents the head of the postglacial rock gorge entered by Eagle River a mile below Pando; *b* indicates the position of the probable preglacial course of Eagle River. The dotted line represents the position of the moraine of the glacier which came down Homestake Creek.

From the edge of the Lake Fork moraine down to the mouth of Little Union Gulch, Arkansas River has a flat from half a mile to a mile wide. This flat has been cut by the river into the valley deposits.

GLACIAL CHANGES IN DRAINAGE.

Two clear cases of changes in drainage due to glaciation were worked out in this region.

EAGLE RIVER VALLEY.

Eagle River, 1½ miles below Pando (fig. 3), enters a narrow rock gorge about 3 miles long. In this gorge the stream, although of considerable size, has cut itself only a shallow valley, which is clearly very young. Just west of the point where the stream leaves its broad valley for the narrow gorge there is a low, broad col (fig. 3, *b*), filled with drift, beyond which lies Homestake Creek, which has from this point down a much larger valley than its size would require.

The history of the change seems to be as follows: As the ice of the last glacial epoch came down the valley of Homestake Creek it pushed across the gorge then occupied by the Eagle (fig. 3, *b*), and by obstructing the stream ponded it and caused it to find a new outlet to the north. On the retreat of the ice a drift dam was left across the old valley, and the Eagle continued to occupy its new channel as far as Redcliff, where it reenters its old valley.

GLACIAL CHANGE IN DRAINAGE IN ARKANSAS VALLEY.[a]

In preglacial times Arkansas River must have flowed at the foot of the rock slopes of mountain ranges on either side, and had a well-developed valley. With the advance of the ice of the older epoch of glaciation, the normal course of the stream was disturbed. From the valleys of Lake and Clear creeks the glaciers of that epoch pushed eastward until they reached the river. Advancing still farther, the ice forced the stream eastward, and the river, abandoning its old course, was compelled to find a way of escape to the east of the ice lobe which blocked its valley. This blocking forced the stream up onto the rock slope of the east valley wall, and here it intrenched itself (fig. 1, *e*). It is possible, even probable, that shallow lakes were formed above these dams, but the rapid débris-charged streams would have quickly filled these lakes, so that there is little probability that any considerable lake ever existed here.

Between Lake and Clear creeks Arkansas River was not pushed eastward by the ice, though it now flows against the rocky east valley wall. Borings in the terraces in this area show that the rock surface below the gravels declines to the west for a considerable distance from the present stream, to what is doubtless the preglacial axis of the Arkansas Valley. The preglacial Arkansas must therefore have cut across the area now occupied by these terraces and by the moraines of the Lake Creek and Clear Creek systems, joining its present channel somewhere south of Clear Creek.

The river, pushed over to the east by the ice from Lake and Clear creeks, may have had at first a great loop to the west between these points. If so, the bend may have been cut off by piracy or it may have been crowded over between these ice lobes by fluvio-glacial deposition.

POSSIBLE CHANGE IN DRAINAGE IN EAST FORK OF ARKANSAS VALLEY.

Since the field work of this report was finished, evidence of the existence of a deep channel in the rock surface northwest of Lead-

[a] Prof. L. G. Westgate, of Ohio Wesleyan University, was studying this problem when the writer reached this portion of the field, and had already worked out its essential features. With his general conclusions the writer agrees. (See Jour. Geology, vol. 13, 1905, p. 294.)

ville has come into the hands of S. F. Emmons, of this Survey. He suggests that this channel is an old valley of East Fork of Arkansas River. The hypothesis is offered that the ice of the older glacial period, advancing from Evans Gulch, pushed westward beyond the base of the mountains and forced East Fork of the Arkansas northwest to the base of the rock spur. Here the stream established itself and the old valley was filled by outwash during the ice retreat. The mouth of the present valley of the stream has never been cut to depths equal to those of the gulches to the south, as is shown by the rock outcrops in its bottom, into which only a shallow channel has been cut. This cut is doubtless the work of the stream in postglacial times. The old stream may have joined the main stream of the Arkansas at about the position of Malta, but this can not be determined without knowledge of the rock surface in this vicinity.

POSTGLACIAL EROSION.

In the rock valleys, left bare of loose material by the last glaciers, we may see how trivial has been the rock cutting by the streams since the glaciers retreated. Occasionally a stream with a very steep gradient or with favorable rock conditions has cut a postglacial gorge 20 to 30 feet into the rock, but usually there is only a shallow channel.

The amount of material removed by stream cutting is very small as compared with the amount loosened by weathering and moved by gravity. Wherever there are steep cliffs there are talus heaps, and in some places the amount of this talus is enormous. In Willis Gulch, of the Lake Creek system, the whole east wall of the cirque head is deeply buried beneath talus which shows the crescentic ridge forms of "talus glaciers."

Beyond the limits of the glaciated areas postglacial stream cutting has accomplished more than in the glaciated regions. The low terraces, built by the extraglacial streams when they were overloaded, have since been vigorously attacked by these same streams. Where the low-terrace gravels occurred in narrow gorges they have all been removed, except occasional patches. Where they were laid down in more extended flats the streams have now intrenched themselves as much as 30 feet into the gravels.

PART II.

SPECIAL CONSIDERATION OF PARTICULAR AREAS.

ROCHE MOUTONNÉE CREEK SYSTEM.

Although most of the system of Roche Moutonnée Creek, locally known as Cross Creek, lies beyond the limits of the Leadville quadrangle, one of its cirques and part of its main valley are contained in the northwest corner of the quadrangle.

The cirque just east of the Mountain of the Holy Cross is one of the most perfectly developed cirques in this region. Broadly U-shaped, the walls at the side and head rise steeply above the valley floor. Very little talus occurs at the base of the slopes, and the whole valley is exceptionally free from loose material. The rock floor has scarcely any covering and is smoothly polished and striated. In a number of basins gouged out of the solid rock by the ice are small lakes.

The main valley of this creek well deserves the name of Roche Moutonnée Creek. For several miles above the terminal moraine the valley bottom is covered with beautifully developed roches moutonnées. These differ in size; some are of considerable height and are so smoothly and symmetrically shaped and have slopes so steep that it is difficult for one to reach their tops.

No heavy-drift deposits occur in this valley within the Leadville quadrangle, but beyond the northern boundary of the quadrangle there are extensive morainic deposits. The southeast wall of the valley, however, shows no distinct lateral-moraine ridge until the terminal moraine is approached. One finds in places on this wall patches of scattered bowlders or a thin layer of drift, but no extensive, continuous moraines.

On the northwest side of the valley, on the contrary, a well-developed lateral moraine runs far up the valley. It is 500 feet above the stream in places, and from the opposite side of the valley presents the appearance of a remarkably smooth, even-crested bench. At one place a cut in this ridge shows it to be merely a layer of drift 50 feet thick, lying against the rock wall, but this is evidently not the case through most of its length.

At the point where the valley enters the Paleozoic terranes the ice lobe curved to the north around the nose of the Paleozoic rocks, and here the lateral moraine loses its distinctive form, although considerable drift rests on this slope. Beyond this nose the lateral moraine

resumes its ridge form, swings in a broad curve to the northeast, and merges gradually into the flattened terminal moraine which lies beyond the limits of this quadrangle.

ROCK CREEK SYSTEM.

An ice system lay in the valley of a stream locally known as Rock Creek, between Roche Moutonnée and Homestake creeks. It consisted of a large primary lobe fed by two tributary cirques from the northwest side, one of which does not appear on the map (Pl. I). The main valley shows well the broad U shape so characteristic of severely glaciated valleys. The ice at the head of this system was separated only by a broad, low col from the ice of the Homestake system. At the time the glaciers were active this col was undoubtedly covered with névé and presented a continuous snow field connecting the two systems.

The valley at the upper end was severely eroded by the ice, for the bare unweathered rock appears almost everywhere in the bottom. Little postglacial talus has accumulated anywhere along the valley sides. In the bottom are a number of lakes, the basins of which were gouged out of the solid rock by the ice.

Northwest of the head of this valley there is a deep, well-developed cirque (the Leadville topographic sheet, base of Pl. I, fails to indicate it), which joins this system from the northwest. This cirque is even more severely glaciated than the head of the main valley, and shows bare walls and floor, with lakes in rock basins.

On the southeast side of the Rock Creek trough the ice limit is not well defined for some miles below the head of the valley, the weathering of the rock and the movements of talus having obliterated most of the glacial features. On the northwest side, however, the ice limit is everywhere sharp and is easily located by the shape of the valley, by the presence of smoothed surfaces of rock, and by a beautiful lateral moraine.

A second tributary lobe of ice entered the main valley from the northwest some 3 miles below its head. Here the ice action was not severe and no well-marked cirque resulted. The ice limit is not sharply defined and the valley was never very well cleaned out. The lower end of this valley has considerable heavy drift.

Just above the junction of this tributary with the main valley, a fine lateral moraine appears in the latter. It runs directly across the lower end of this tributary and shows that the ice was still very vigorous in the main valley after ice had ceased to come out from the tributary. The ice, in crossing the mouth of the tributary, built up its lateral moraine, and in so doing obstructed the side valley. As a result there is now a considerable flat which was developed behind this lateral-moraine dam. The lateral moraine at this point

has a height, on the outside, of 60 to 100 feet, and the material lies at an angle of 35°. The inner slope is here about 25°, and the crest of the ridge is 600 feet above the valley bottom.

This lateral moraine runs for several miles with a uniform slope and an unbroken crest, and is a most striking topographic feature of this system. Bowlders up to 10 feet in diameter occur in considerable abundance over the surface of this ridge.

The lateral moraine on the southeast side of the stream appears farther down, beyond the boundary of the quadrangle, and nowhere reaches the perfect development of the opposite moraine, though it is a well-formed ridge toward its lower end.

There is no well-marked terminal moraine in this system. At the point where the lateral moraines begin to converge the stream has a very steep gradient, and the drift was probably carried away as fast as it was deposited. The stream bed beyond the drift is filled with bowlders which may be of glacial origin, but no distinctive drift of the terminal-moraine type is found.

HOMESTAKE CREEK SYSTEM.

Except one the Homestake Creek system was the largest on the east side of the Sawatch Range. At its maximum the ice covered an area of about 46 square miles, and its maximum length was more than 17 miles.

The main body of ice lay in the valley of Homestake Creek, but 15 well-developed cirques and a number of minor valleys contributed ice to this system. These cirques head near the tops of the ridges which surround the Homestake Creek basin, and in many cases are separated only by low cols from the cirques of the other systems.

SOURCES OF THE ICE.

Source 1 heads northwest of Whitney Peak, and is separated only by a low col from the head of the Rock Creek system. The cirque has a broad U shape. The side walls are, in general, not very steep, but the head wall rises abruptly and terminates in a row of serrated peaks, which divide this system from the Roche Moutonnée and Rock Creek systems. There is little talus at the base of the slopes; yet the topography does not give the impression that the glacial erosion was severe. The shoulders and knobs of the walls are rounded, but not intensely so, and few polished and striated surfaces occur. The valley bottom consists of a number of smoothed rock knobs, and is not at all level and floorlike. Three small lakes occur near the upper end of the valley, with basins apparently in the solid rock.

Source 2 is a hanging cirque, its junction with source 1 being several hundred feet above the floor of the latter. It has flaring side walls,

but a rather steep head wall, which, like that of source 1, terminates above in a row of sharp needles. The walls do not appear to have been severely glaciated. Talus has everywhere accumulated to a considerable extent, and the rock floor where it is exposed is not well polished or smoothed. It was merely a collecting basin which was somewhat eroded.

Source 3, like 2, is a hanging cirque, and its lower end does not reach below 11,900 feet. It contains little talus, and its head and side walls are well shaped, although few smoothed and polished surfaces remain. It ends rather abruptly at its junction with the main valley.

Between cirques 2 and 3 there is a "talus glacier" about 100 yards wide and 50 feet high, extending in a long tongue out into the valley. The front and sides of this tongue are very steep, and the blocks are large and angular.

Source 4 has a broadly U-shaped trough with steep head walls. Below an elevation of 11,300 feet the valley is free from drift and talus, and many smoothed and polished rock surfaces outcrop. The cirque is not cut down to the same level as the valley which it joins, but has a very steep gradient at the point where its floor joins that of the main trough.

At the 11,300-foot level in this cirque there is a recessional moraine of bowlders and angular blocks. Above this moraine the cirque floor contains considerable drift and talus. On the northeast wall there is an even-crested ridge of bowlders sloping back from the terminal moraine, which is the lateral moraine of this recessional stage, contemporaneous with the terminal recessional just mentioned.

Source 5 is not a well-developed cirque, although the head has a good U shape. The side and head walls have occasional marks of glaciation, but are not conspicuously smoothed or polished. Considerable postglacial talus has accumulated, and this tends to lessen the impression of great intensity of ice action. The bottom of the valley contains a considerable lake, which has its basin in the solid rock. The valley floor is not well smoothed, but contains numerous rounded rock hummocks, which are often polished and striated. To one at any particular place the floor seems much more severely glaciated when looking downstream than it seems when looking upstream, for plucking has left many sharp points of rock on the lee side of the rock knobs, while the stoss sides have all been smoothed.

Sources 1, 2, 3, 4, and 5 all sent their ice into a single valley, tributary to Homestake Creek. Below the junction of these cirques this tributary valley is strongly glaciated. No areas of heavy drift occur in the valley bottom. In many places the stream flows on rock, though more often the channel is filled with bowlders. For some distance above Gold Park the stream falls very rapidly, and the

water power was here used to a considerable extent when Gold Park was a flourishing mining camp.

Between the ice in this valley and that of West Fork there was deposited a considerable body of heavy drift. In the area where the edges of the two lobes came together the ice action was naturally weak, and over the flat top of the dividing rock ridge the ice must have been spread out in a rather thin sheet. Its transporting power was thus lessened, and the glacier deposited here a large quantity of drift, which has the form of a sharply defined interlobate ridge for some distance below the point where the ice lobes joined. This ridge flattens out below, and grades into a thin sheet of drift which caps the whole of this flat ridge. Bowlders up to 10 feet in diameter are thickly scattered over this drift.

Source 6 is broadly U-shaped and has three minor heads. These heads, though small, are all U-shaped and show evidence of somewhat intense ice action. The side and head walls are all steep, and little postglacial talus has accumulated at the base of the slopes.

Below the junction of these heads the valley is broad and trough-like. The side walls, although well rounded, do not now show striated or polished surfaces, but this may be due to the gneissic character of the country rock, which in general has failed to retain its glaciated surface.

All loose material was removed by the ice from the bottom of the valley, and it now contains few bowlders and little talus. In several places the stream flows through postglacial cuts in the bed rock, one of which is 30 feet deep in the fractured gneissic rock. Beginning at the 10,600-foot level, there is a low backbone of rock which extends between the two branches of the creek, and this ridge has been more or less moutonné.

In the valley bottom, along the north side, between the elevations of 10,000 and 9,300 feet, there is a long, narrow deposit of drift, parallel to the stream. This drift has not the characteristic moraine topography, and is probably only a thin sheet.

Sources 7, *8*, and *9* have much the same characteristics. All show the effects of vigorous glaciation, are U-shaped, and are comparatively free from accumulations of postglacial talus. Numerous bare surfaces of rock appear, which often show smoothed and striated surfaces.

The lower portions of these cirques are heavily timbered, and all but the general features are obscured.

Source 10 includes the valley of Middle Fork of Homestake Creek. At the head of this cirque, above the lake, the walls rise precipitously, with little talus. The rock walls of granitic gneiss do not take polishing or striæ well, but the slopes are well rounded and no angular outcrops appear below the well-defined upper limit of

glaciation. The lake in the cirque seems to have its basin in bed rock which everywhere presents well-cleaned-off, rounded surfaces. The valley is broadly U-shaped, and the ice limit along the sides is well marked where it crosses spurs running down to the valley.

The southernmost tributary cirque on the west side of this valley is a small hanging cirque, which joins the main trough about 500 feet above the bottom of the latter.

In the valley, just above its junction with East Fork, there is a lake almost a mile long. This lake is shallow, and the upper end has been filled in for several hundred yards by the silt from above, making a low, marshy flat through which the stream meanders. For about 2 miles below this lake the valley contains numerous moutonné hills of rock, some 20 feet in height.

Above the junction of Middle and East forks the east wall of the valley is of bare rock, smoothed and moutonné, and bears scarcely any talus. This wall is almost unbroken by draws, and the rock is generally smooth and polished. The west wall also is practically free from talus, but is broken by two tributary cirques. The lower of these is a hanging cirque and is not deeply eroded, but is divided into two or three heads by minor spurs. The inaccuracy of detail in the topographic map at this place makes close mapping of the ice limit impossible.

Source 11 comprises the trough of East Fork. At its upper end this valley forms a beautifully developed cirque. This is broadly U-shaped, with the head and side walls rising almost perpendicularly for more than 1,000 feet above the valley floor. Very little talus has accumulated, and the moutonné bed rock appears in many places. Three lakes occur in this cirque, apparently in rock basins. One of these has been almost completely filled up with silt, forming a marshy flat at its upper end.

Source 12 was placed on the map geographically, without reference to the contours as given. This cirque heads back in an almost southerly direction and is deeply eroded, with little loose material in the bottom. The head and side walls rise abruptly on all sides, and in many places the ice limit has been obscured by the weathering of the rock walls and by the talus from above. The cirque bottom contains one lake, the basin of which is carved out of the bed rock. Around the outlet of this lake the surface of the rock is talus covered, but the lake has some depth, and numerous rock outcrops below show the talus covering to be thin.

In the main valley, below the junction of sources 11 and 12, the ice moved with great vigor, cleaning out and excavating the bottom and sides of the trough, and leaving the hard, unweathered surface of the granite everywhere exposed. On the west side of the stream the ice reached almost to the divide on both sides of the ridge, and

left only a sharp, narrow backbone untouched. At about 10,900 feet the ice from opposite sides of this ridge joined, covering the ridge below this point.

Source 13 lies just west of Homestake Peak and contained a small glacier tributary to the main ice lobe. This cirque, U-shaped at its head, is a hanging cirque, and loses itself in the main valley at an elevation of about 10,600 feet. The impression of severe glaciation is marred by the considerable accumulations of postglacial talus. Northeast of this cirque the topographic mapping is inaccurate, and the limits of the ice were dotted in without regard to the topography as mapped.

The main valley of the Homestake, from the junction of Middle and East forks down to Gold Park, is strongly glaciated. Numerous roches moutonnées appear in the valley bottom, and the sides are cleaned off and rounded. Although locally patches of bowlders occur, numerous outcrops of rock and numerous bosses of glaciated rock make this area one of light drift.

Source 14 lies north of Gold Park and southeast of Whitney Peak. Although some ice movement took place in this area, it is not a well-developed cirque, but was a broad collecting field divided into two shallow heads which have been shaped, but not deeply excavated, by the ice. Many scattered bowlders lie over the valley floor, but owing to the absence of steep walls there have been slight accumulations of talus.

About a mile below the head of this cirque there is a lake in the gulch bottom, which was formed by the ponding of the stream behind accumulations of drift in the valley.

Source 15 lies about 3 miles northeast of 14 and joins the main trough from the west. It heads at an elevation of 12,000 feet and is shallow, and the ice from it was therefore less effective than in the cirques which head much higher. Only a small area just at the head of the cirque shows severe glaciation.

DRIFT AREAS AND MORAINES.

In the lower ends of sources 14 and 15, and along the upper edge of the glaciated portion of the northwest wall of the Homestake Creek gorge, there is a body of heavy drift which extends from a point above Gold Park down to the point where the ice limit reached the 10,200-foot level. Although rock outcrops occur here, almost the whole of this area is covered by drift of sufficient thickness to mask the topography of the rock wall. Large bowlders are scattered over the surface, one 40 feet in diameter being found. This heavy-drift area does not reach down to the valley bottom, but lies along the upper edge of the glaciated area, the lower edge being from 400 to 500 feet above the stream.

On the southeast valley wall is a body of heavy drift occupying much the same relative position and having much the same characteristics as that on the northwest side. It extends from the upper side of source 13 down to the point where the ice limit reaches the 10,000-foot level. Bowlders, large and small, are everywhere scattered over the surface, and numerous kettles, forming ponds or marshes, dot the area. Some rock outcrops occur, but they occupy only a small part of the whole area.

The upper limit of glaciation along this side of Homestake Creek is not everywhere sharply defined. In some places it can be traced only by the presence of scattered bowlders.

About 2½ miles southeast of Gold Park is a cirque-shaped valley which does not seem to have been affected by the ice of the last epoch. It will be referred to again later (p. 36). Below this cirque the upper limit of the ice is marked by a definite lateral-moraine ridge for more than a mile. This ridge has an outer slope 50 feet high in places, although 15 to 30 feet is a more common height. Its surface contains many bowlders, and numerous kettles occur both in the lateral moraine itself and just outside of it, where the drift has dammed up small streams. At the point where the ice limit reaches an elevation of 10,800 feet this ridge form of the moraine disappears and the ice limit is marked only by scattered bowlders and occasional glaciated outcrops.

The upper limit of the ice continued northward in this way to the point where it crossed the 9,800-foot contour, at which place it curved sharply to the east around the nose of the ridge and pushed up the Eagle Valley as far as Pando. East of this nose the drift again develops a ridge form at a point where it crosses a draw. This ridge is 30 to 50 feet high and has bowlders up to 6 feet in diameter. There is only a shallow post-glacial cut through this ridge. Beyond this draw the ridge form of the drift disappears and the drift lies against the slope of the cliff and is often mingled with talus from the steep slopes above. The limit of the ice becomes lower and lower and finally swings to the southeast just beyond the deposits of terminal moraine.

On the northwest wall of the Homestake Valley, below the patch of heavy drift, the upper edge of the ice lay along the rock valley wall. There is no lateral-moraine ridge of any kind, and the height to which the ice reached is shown only by the rounded appearance of the rock wall. The wall shows no smoothed or striated surfaces, but all projecting points and angles have been subdued. This bare rock wall continues northward to the limit of the Leadville quadrangle. Beyond this the ice limit swings somewhat to the northwest, following the course of the Homestake Valley. Some heavy drift occurs against the rock on the west, but this has no typical drift topography

and is mingled with talus from the cliff above. Beyond the Leadville quadrangle the ice edge descended rapidly on both sides of the valley, and all evidences of glaciation end where the Homestake joins Eagle River, just west of Redcliff. The ice, ending in the narrow valley, left no terminal moraine, for the swift stream carried the drift away as fast as it was dropped by the ice. Some heavy drift occurs on the east side of the valley beyond the quadrangle limit, but it consists mainly of large bowlders lying in a col on the valley side and has no drift topography.

MAIN VALLEY.

The main valley of the Homestake, below Gold Park, has the features one would expect to find in a valley formerly occupied by a glacier of this size. The bottom is broad and broken only by occasional roches moutonnées, some of which rise 150 to 200 feet above the stream. Some mounds of what appears to be heavy drift occur, but sections in many of these show them to be bosses of rock with a thin veneer of drift. One patch of heavy drift about one-half mile long and one-fourth mile wide lies just below the point where the 9,000-foot contour crosses the valley. Below this there is an alluvial flat, which was probably built by the stream while it was removing some obstruction below.

At the bend of Homestake Creek, 2 miles south of the edge of the quadrangle, there are remnants of terraces on either side of the present river flat. These terraces stand from 12 to 15 feet above the stream, and are composed of gravel, the constituents of which are less than 6 inches in diameter. Occasionally larger pieces of rock occur, but these may be talus from the cliff above. These terraces seem to be remnants of a valley train which was built from the edge of the ice during its retreat and which has since been almost completely removed. The stream is a vigorous one and is now cutting into these terraces.

Along the west and southwest side of the ridge between Homestake Creek and Eagle River the limit of glaciation is hardly traceable. Doubtless the ice from the Homestake Valley, meeting this ridge almost at right angles, became stagnated along the side and had little effect on it. No definite line to which the ice reached could be drawn, and only scattered bowlders show that the ice once covered the lower slopes.

This ridge, opposing the ice in the Homestake Valley, sent most of it down the gorge to the north, but a lobe was pushed to the south, to a point one-fourth mile above Pando. Here a thin terminal moraine was deposited across the valley of Eagle River. This terminal moraine is of very slight relief, and although it has hummocks and kettles they are of no great size. After the deposition of this

drift the ice retreated to a point one-fourth mile north of Pando, where it deposited a very considerable terminal moraine across the valley of the Eagle. This terminal moraine is 80 feet high at the west side of the valley, but becomes lower toward the east. The drift is composed of bowlders which correspond to the rocks in the valley of Homestake Creek, and the topography has a modified hummock-kettle character. The outer face of this ridge shows roughly a benchlike arrangement, three benches appearing, one above the other, as though the ice had built one bench and then retreated a little way to build others above the first. Beyond the terminal moraine the waters of Eagle River were ponded between the two distinct moraine deposits, and a flat was built up. Outside of the later moraine, in this flat, there is a considerable body of gravels, probably deposited as an outwash apron.

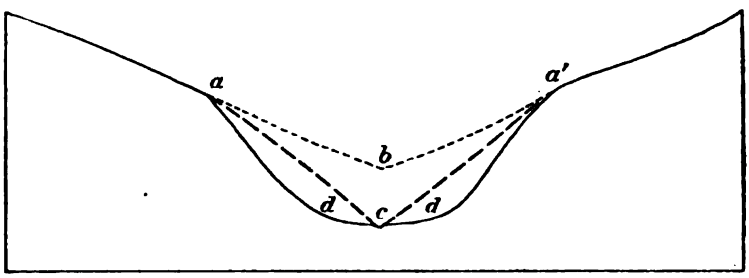


FIGURE 4.—Diagrammatic cross section of Homestake Creek valley. *a, b, a'*, Probable preglacial shape of valley; *a, c, a'*, preglacial shape of valley if it was not deepened by glacial erosion; *a, d, c, d, a'*, present shape of valley; *b, c*, probable glacial deepening of valley; *a, d, c*, material removed by glacial erosion if valley was not deepened by the ice; *a, b, a', d, d*, material removed by glacial erosion if valley was deepened from *b* to *c*. Horizontal scale, 1 inch=one-half mile. Vertical scale, 1 inch=one-fourth mile.

Within the inner ridge the valley bottom contains heavy drift for about a mile to the northwest. This drift is remarkably free from bowlders and has little of the drift topography.

The valley of Homestake Creek, viewed at a point about 5 miles below Gold Park, is broadly U-shaped and shows the effect of glaciation on the walls for about 1,000 feet above the stream. All spurs have been truncated and the walls and floors of the valley have been smoothed and rounded. This broad U shape does not accord with the cross section of the normal stream-cut valleys of these mountains, and the amount of material removed by the ice in changing the valley section from a V shape characteristic of the unglaciated valleys of this region, to a U shape was great, even if there was no deepening of the valley. It is certain, however, that this valley was considerably deepened by glacial erosion, as is evidenced by the smoothed and montonné condition of the floor rock in numerous places, and that as shown in the diagram (fig. 4, *d, d*) the

amount of erosion was considerably greater, perhaps several times greater, than it would have been if there had been no deepening.

The amount of postglacial weathering in this valley is small. Only at the base of the steepest slopes are there accumulations of talus, and the smoothed rock surfaces appear hard and fresh. The stream has here and there cut its channel 10 to 15 feet into a rock obstruction in its bed, but its course is usually in a bowlder-strewn channel in the flat valley bottom.

OLDER GLACIATION.

From observations made in various parts of the Leadville quadrangle it is certain that many of the valleys were occupied by glaciers during two distinct epochs, one much earlier than the last. This was the case with the valley of Homestake Creek. East of the area occupied by the last glacier, at a point 2 miles west of Pando, there is an area covered with bowlders left by the older glaciers. This area is beyond the crest of the ridge which limited the ice of the last epoch, but if the last glacier had been 100 feet thicker, it would have overspread the valley wall at this place and would have left drift in about the position where these bowlders now occur. The older drift here consists merely of scattered bowlders lying upon the rock wall or on the very thin soil of this slope. They are composed of rocks which occur far up the valley of Homestake Creek and not of the rocks of this ridge. No sections were found which showed any body of drift at this place. The bowlders are deeply weathered and many of them are falling to pieces, and their surfaces long ago lost any distinct glacial markings which they may have had, but their lithological character and topographic position indicate their glacial origin.

Five miles farther up the valley of the Homestake, southeast of Gold Park, there is a cirque opening into the main valley which shows a decided glacial shape, but does not seem to have been occupied by ice during the last epoch. The walls and bottom are covered with talus to a greater extent than are the other cirques of this system, and the moraines of the last ice epoch lie across the mouth of this valley. A possible explanation of the formation of this cirque is that the ice of an older epoch excavated it and gave it its shape, but that the ice of the last epoch did not accumulate here in sufficient quantity to renew glaciation.

MITCHELL SYSTEM.

The Mitchell system lay in the valley of the creek that joins the Eagle one-fourth mile north of Mitchell. It headed in a single broadly U-shaped cirque from which the ice went down a narrow valley at its lower end. For the upper end of this valley the topography of the map (Pl. I) is so imperfect that only approximate mapping of

the glaciated area was practicable. The cirque has two principal heads, one reaching back to the northwest and the other to the southwest. Nowhere in this cirque was the glaciation intense. The valley lacks the gouged-out appearance presented by the troughs of the larger glaciers, and its bottom and sides have quantities of postglacial talus. In the floor are numerous hillocks of rock 50 to 100 feet high, which, although shaped somewhat by the ice, are not strongly moutonné. The upper lift of glaciation around the head of the cirque is difficult to locate on account of the abundant talus. Only an occasional rounded shoulder of rock gives a clue to the height to which the ice reached.

Along the north wall of the valley the line to which the upper edge of the ice reached is in general indefinite, and can for the most part be located only by scattered bowlders. At about the point where the upper limit of glaciation as shown on the map crosses the 10,700-foot contour a draw runs back from the main trough. Across this draw a lateral-moraine ridge 30 feet high was built by the ice. Behind this ridge a small stream was ponded and a marshy flat developed. The moraine on this side of the stream locally takes the form of a broad bench of drift, about 75 yards wide. The upper edge of the glaciated area on the south wall is nowhere more than 200 feet below the crest of the ridge, except near the head of the cirque. The supply of ice seems to have been sufficient to fill the valley brimful on this side. For about 2 miles from the cirque head the ice developed no lateral moraines along the south side of the valley. Its upper limit is marked by scattered bowlders only, and these are often difficult to distinguish, lying as they do among the talus blocks. Where the upper edge of the ice reached the 11,500-foot level, however, there is a slight sag in the crest of the ridge, and the ice crowded over at this place and sent a short tongue down into the valley to the south, making a terminal moraine on the slope. This moraine is of considerable thickness and consists mostly of large bowlders. It has numerous kettles and the topography characteristic of terminal moraines.

Beyond this sag in the ridge the upper border of the glacier followed rather closely the top of the ridge—sometimes pushing a little way over it—to Mitchell. This system, ending in the narrow gorge, has no typical terminal moraine, although the valley bottom at the lower end is covered with drift, which has little of the irregular moraine topography and is apparently of no great depth.

Just beyond the edge of the glacier a very considerable alluvial fan was built out into the valley of Eagle River. It may have been built as an outwash apron from the edge of the Mitchell glacier and have been considerably more extensive formerly than it is at present. The Eagle has now made a cut of about 20 feet into this deposit of gravel, which corresponds in age to the low-terraced gravels observed below the moraines of many of the glacier systems.

GLACIER EAST OF MITCHELL.

Two miles east of Mitchell there is a north-south valley which joins the East Fork of Eagle River. This valley was occupied for 2 miles of its length by a feeble glacier. Its head had an altitude of only 11,700 feet, and the existence of a glacier here was due more to the protected north slope of the valley than to its elevation. The valley is broadly U-shaped, but does not give the impression of very severe glaciation, for the slopes are covered with talus and little bare rock shows. The greater part of the glacial excavation of this area was probably accomplished during the earlier epoch of glaciation, while the glaciers of the last epoch were feeble.

The terminal moraine of this system lies on the slope southeast of Eagle Park and consists of an area of drift with a rough kettle-hollow topography. The deep weathering of some of the morainal material at this place suggests the possibility that some of it may be of older glacial age, although it has not been mapped as such.

CRANE PARK SYSTEM.

The main lobe of this system lay west of Crane Park, although the system was peculiar in having three distinct termini and in occupying the valleys of four separate streams.

SOURCES OF THE ICE.

Source 1.—The northernmost head of the system lay east of Homestake Peak and sent its ice due east. The head of the glacier was double, but the dividing ridge was almost wholly covered by the ice. This double cirque is not well developed. At the head the rock walls are covered with talus and few smooth surfaces of rock appear. There is little bare rock about the lake in the southernmost of the two heads, and the lake basin may or may not have been hollowed out of the rock.

The ice limit on the north side of the valley is often difficult to locate, as it is indicated only by scattered bowlders. In a few of the more favorable topographic locations feeble lateral-moraine ridges appear for short distances. At the lower end of this lobe the topographic map (Pl. I) lacks detail and has been disregarded to some extent in mapping the position of the moraines.

As seen from below, the terminal moraine of this lobe appears as a great dam or plug across the valley. The outer border is crenate and consists of three lobes, as though the ice edge had reentrant angles. The terminal moraine is of the extreme hummock-kettle variety. Bowlders up to 15 feet in diameter abound on the surface. Within the terminal moraine proper the heavy-drift area extends up the valley for some distance, and though lacking the very irregular topog-

raphy of the terminal moraine the material is the same. Some undrained depressions occur, but in general the relief is mild.

Source 2 is a much more pronounced cirque. Its side and head walls are steep and fairly free from talus, and in many places the bed rock shows smoothed and striated surfaces. Two spurs running down into the valley from the northwest head wall divide the cirque into three lobes, but the ice was continuous over these spurs, which were worn by it. The cirque bed is free from talus and drift, and the rock floor is smoothed and moutonné. The lakes mapped have rock basins.

Between sources 1 and 2 there is a well-defined interlobate moraine ridge, 30 to 50 feet high, which marks the line of junction of the ice lobes from the two cirques. Below the end of this ridge there is nothing to indicate whether or not ice from source 2 went down to help make the terminus below source 1, but no large percentage of the ice from source 2 got into the other cirque, as its own outlet is lower. The ridge west of Tennessee Pass served as a wedge to keep the ice of the two lobes separate. On this ridge the ice rose almost to the top, but was not quite able to cover it.[a] The ice south of this dividing ridge swung down to the valley and formed a perfect lateral-moraine ridge, 30 to 60 feet high, having an almost unbroken crest down to the point where it merges into the terminal moraine.

The terminal moraine is strongly developed. As seen from below, it rises from the flat in a steep wall, 100 to 150 feet high, with the crest still higher. The sky line is not like that of a lateral moraine, being much more broken. Within this outer wall is a broad area of the most typical terminal moraine. The topography is very irregular, hillocks and kettles occurring in great confusion. Many of the depressions still contain ponds, while others have been silted up to form marshes. The moraine surface is covered with bowlders, most of them less than 6 feet in diameter.

On the south side of this lobe the moraine ends in much the same way as on the east, the drift having more of the characteristics of a terminal than of a lateral moraine. It has an outer crest which presents not the unbroken lines of a lateral moraine but rather the topography of a terminal moraine. The south edge of this lobe in the light-drift area lies along the ridge which separates it from source 4 and reaches almost to the top of this ridge. The wall is not free from talus, and the limit reached by the ice can be determined principally from the rounded cross section of the valley below this line.

Source 3 has a fan-shaped head, and falls short of symmetrical development as a cirque in that the head is divided into five subdivisions by spurs which run down from the west wall to the valley

[a] The topographic map is inaccurate at this place.

bottom. The valley contains considerable talus and drift, and the gneissic rock has failed to hold striæ or polishing. Scattered blocks, 15 feet in diameter, occur. The upper limit of the heavy-drift area is fairly well defined here. The heavy drift appears as a mound in the center of the trough, and from the head of this mound the heavy-drift line swings down to the valley sides to the north and south.

Source 4 is intimately connected with source 3, in that it receives part of its ice from the head of 3. The col at the head of source 4 is much lower than the map shows, and ice came down both valleys from 3. The symmetry of this valley is destroyed by a spur which runs down into the cirque from the northwest side. The slopes have a good deal of talus and little bed rock appears on the floor, except at the very head.

The lower half of this cirque shows the characteristics of a typical glaciated valley much better than the upper half. The lateral-moraine ridges on either side of the valley are well formed and in places rise 400 feet above the valley between. The north lateral moraine has a rather broad crest and not much of an outer slope, and lies as a great bench of drift against the rock wall. The south lateral moraine has a better defined crest.

At the lower end of the system the lateral moraines flatten out into a feeble terminal moraine. This lobe, unlike the one just to the north, deposited no great amount of material as terminal moraine.

OLDER DRIFT.

That the area of this system was occupied by ice of the older epoch of glaciation is shown by an occurrence of older drift 2 miles southwest of Mitchell, between the two forks of the stream. (The north fork is not shown on the map, Pl. I.) This older drift area extends for three-fourths of a mile below the edge of the new terminal moraine. There is evidently a considerable body of drift here, although no sections were found to show its depth. Bowlders up to 6 feet in diameter are scattered over the surface. The materials are much oxidized and more deeply decayed than those of the last drift, and many of the bowlders are falling to pieces. Although many bowlders show subangular forms, no certain striæ were found. The surface here has an erosion topography, and all signs of kettles or of a ridge form have been removed. The new drift comes down to, and probably overlies, the older drift, and may cover a considerable part of the whole area of older drift.

LAKE FORK SYSTEM.

This system of glaciers extended from the crest of the range to Arkansas River. Ice gathered in eleven cirques and united to form a single lobe in the valley of Lake Fork.

A. ROCK SURFACE IN CIRQUE 1.

Although glaciated, the loose material was not all removed, and the preglacial decay was probably very deep.

B. BOWLDERS IN HEAVY-DRIFT AREA ABOVE BUSK.

SOURCES OF THE ICE.

Source 1 is a well-developed cirque with head walls rising almost perpendicular 1,000 feet above the cirque floor. Much talus and some drift bowlders occur in the valley, but in many places the walls are so steep as to be free from loose material. The rock walls are striated and polished in numerous places, and all projections are rounded. At the base of the head wall a rather large lake lies in a rock basin.

Sources 1 and 2 are separated from each other for only a short distance at their heads. At an elevation of about 12,300 feet the ice covered the dividing ridge, and a little lower the cirques join. This ridge was severely worn and shows striæ pointing obliquely down into the valley of each of the cirques.

Source 2 is much like 1 in character. It has even steeper walls, which on the northwest side rise almost vertically for 1,200 feet. The cirque as a whole is well cleaned out, though some postglacial talus has collected below the cliff-like walls. The smoothed bed rock shows at many places on the lower rock slopes. At the foot of the spur which divides source 1 from 2 there is a patch of heavy drift (Pl. II, *B*). It occurs just where an interlobate moraine would be likely to form, and may have been deposited in this way, though it does not take the form of a ridge. Bowlders 15 feet in diameter are not uncommon in this area. Along the southeast wall of source 1 the ice limit is definite for only about a mile from the cirque head. Beyond this, to the point where the cirque joins the main valley, the line to which the ice reached is more or less indistinct, and is marked chiefly by scattered bowlders, although the drift is nowhere of any considerable thickness. Shallow cuts along the railroad show repeatedly that the surface of the rock is deeply weathered and that all the loose material was not removed by the ice of the last epoch (Pl. II, *A*.) The glaciation here could not have been very severe, else this rotten material would have been removed.

On the northwest side of the cirque the limit of glaciation is much more distinct. The walls below, however, are much the same in character as those on the opposite side, since cuts show the arkose and rotten rock at the surface. On this rock wall one-half mile above its junction with source 3 there is an isolated patch of heavy drift high on the valley side. This is probably a coating of only moderate thickness over the rock below.

Source 3 was a broad, rather shallow reservoir of ice. Although the steep head wall would indicate glaciation of some intensity at that place, the imperfectly cleaned-out and shallow lower part of the basin does not strengthen this impression. Considerable postglacial talus has accumulated at the base of the cliffs. The lower end of the cirque was not cut down to the level of the main valley, but is hanging

with its mouth 300 feet above the floor of the main valley. A small patch of heavy drift occurs at the mouth of this cirque, which was probably deposited as a recessional moraine of the retreating ice.

Sources 4, 5, 6, and *7,* although differing considerably in shape, have the same general characteristics. These cirques, with steep head and side walls, were all strongly glaciated. The gneissic rock, however, weathers readily, and all smooth and polished surfaces have been removed. Large quantities of talus everywhere bury the base of the cliffs and extend out into the cirques, which give the impression of having been severely glaciated a long time ago.

Source 8 is a well-developed cirque. It is U-shaped, and the bottom is free from loose material as far down as the heavy-drift line. The walls at the head and sides show the bed rock everywhere and still bear traces of glacial smoothing, though for the most part the outcrops have been somewhat roughened by postglacial weathering. The ridge between sources 8 and 9 is almost covered with heavy drift and forms an interlobate moraine here. On the side of this ridge toward source 9 the drift has a maximum slope of 35°. An occasional outcrop of rock shows this ridge to be composed largely of rock, with a somewhat heavy veneer of drift.

Source 9 has a steep head wall, which shows glaciation almost to the top, but has been much roughened by postglacial weathering. The cirque is broad and free from drift and talus as far down as the heavy-drift line, and the impression given is of rather severe glaciation.

Source 10 is broad and not especially well developed. The shoulders of rock along the valley sides are not notably worn, and the side walls, although without much talus, are not strongly glaciated. The low slopes of the side and head walls show that the erosion effect of the ice was not intense. Although the ice reached almost to the top of the col, the divide is flat topped, and shows no tendency to take the sharp-toothed form seen at the heads of many deeply cut cirques.

Source 11 consists of two shallow, parallel gulches, which were filled by a single ice lobe. The west wall of this cirque is very steep and has been cut back almost to the top of the peak. The cirque as a whole is broad and shallow, and the ice against the west wall was much higher than on the east side. At their upper ends the two parallel cirques are strongly glaciated, but accumulations of talus have obscured most of the rock surface, and the upper limit of glaciation can not be determined closely.

HEAVY-DRIFT AREA.

The heavy drift in this system occurs in irregular patches. In the trough of North Fork one patch begins just above the junction of the streams from sources 6 and 7, and continues in the valley bottom for

2 miles downstream, beyond which it is continuous with a body of drift lying on the north wall. The west end of this drift area is remarkable for the large number of bowlders on its surface, many of them 20 to 30 feet in diameter. Below sources 10 and 11 the drift lies on the north wall as a sheet of varying thickness. The surface, as a rule, is thickly scattered with bowlders, and occasional undrained depressions occur. Another patch of heavy drift occurs on the south side of Lake Fork, at the junction of the North and South forks of the main stream, and extends up the valley side about 600 feet at the curve of the railroad. The drift is of varying thickness. Along the railroad cuts show it to be thin over the rotten and deeply weathered granite beneath, and this condition seems to hold wherever the drift occurs on the steep rock slopes. Between the curve of the railroad and the main stream the slope of the valley side becomes less, and here the drift is apparently much thicker and has the characteristic drift topography which is independent of that of the underlying rock surface.

MORAINES.

Below the junction of North and South forks the trough bottom has a flat one-fourth to one-half mile wide. The rock walls on either side are unlike the walls of most recently glaciated valleys. All outcrops show the rock to be deeply weathered and rotten, and numerous prospect holes show this to be the condition for a score of feet below the surface. This indicates either that the ice of the last epoch did not severely erode the walls of its gorge at this place or that the decay was very deep, for the ice would have removed any superficial layer of decayed rock. This weathering must have taken much more time than has elapsed since the last glacial epoch. Therefore, either the U shape of the trough must be due to the erosion of ice of an earlier epoch or the preglacial weathering of the rock here must have extended to a greater depth than that to which the ice eroded its valley wall at this place. The latter is probably the proper explanation of the weathered condition of the rock. This condition is confined to a limited area in this system of glaciation, and is probably due to some local cause of decay. Two and one-half miles below the junction of North and South forks there is a kamelike dam, one-fourth to one-half mile wide, which extends across the gulch bottom. The material here consists of gravels 2 inches and less in diameter, which were formed of such granitic rocks as the stream is handling at present. This area has a weak morainic topography, with shallow kettles, and may have been formed, during the retreat of the ice, behind a huge block of ice left across the valley below this area. Behind this kamelike dam there is a lake flat, which was probably formed while the stream was cutting an outlet through this obstruc-

tion. At the foot of the mountains the ice was confined by the narrow valley to a width of about a mile. As it escaped the gorge it deployed in a great piedmont lobe more than 3 miles wide. Here the ice built a terminal moraine in the form of a huge crescent. This moraine rises abruptly from the flat, the top being 100 to 200 feet above the plain. The drift here has the characteristic terminal-moraine topography, although the relief for the most part is slight, the hummocks rarely rising more than 15 to 20 feet above the adjacent kettles. In keeping with the weathered and decayed condition of the surface rock in the valleys above, the materials of the terminal moraine are remarkably old in appearance. Only an occasional fresh-looking bowlder appears, and most of the few bowlders on the surface are old and rotten. So far as the materials are concerned, the drift looks like that of the earlier epoch, but the topography is undoubtedly that of the last glacial epoch. On either side of the valley, where the moraines swing away from the rock walls the drift takes the form of a well-defined lateral-moraine ridge with a crest 100 to 200 feet high. These ridges become lower away from the mountains, and gradually flatten out and merge into the terminal moraine.

Lake Fork has its outlet through the terminal moraine to the south. At this place the stream has a cut about 30 feet deep. Above this cut a broad flat formerly extended up the valley about 2 miles and was evidently once a lake. A dam about 30 feet high has now been built across this stream cut and a reservoir formed, which probably occupies about the same area as the former lake. The cut in the drift from which the material for the dam was taken shows the terminal moraine to be composed mostly of fine materials, most of the bowlders being deeply decayed. Lenses of sand occur in the drift, and the disturbed lines of stratification show plainly.

HIGH TERRACES.

There can be little doubt that at the end of the earlier epoch of glaciation there were high-terrace gravels deposited in connection with the older moraines of the Lake Fork system. These gravels, however, were for the most part removed in interglacial time by Arkansas River, although it is possible that the last glacier of this system advanced over some of these old gravels and covered them with newer drift or incorporated them into the new deposits. The old and weathered appearance of the materials of the Lake Fork terminal moraine may be in part due to the presence of much old high-terrace material.

LOW TERRACES.

During the last ice advance Lake Fork flowed south from the ice edge and entered a considerable flat, cut in interglacial times into the

high-terrace gravels. In this flat the stream deposited gravels which are related to the last epoch of glaciation and to the latest moraines in the same way that the high-terrace gravels of the Arkansas Valley are related to the older ice epoch and older drift. They are imperfect'y stratified and are of fresh, unoxidized appearance, and in erosion are as little touched as the last moraines. Lake Fork has cut a postglacial channel into these gravels, which is only a few feet deep at the southern end of their area, but is 15 to 20 feet deep where the gravels join the Lake Fork moraines. The gravels have the slopes of an alluvial fan, its focus at the stream cut in the moraines, and they slope to the south and southeast with a gradient of 3° at the upper end to 2° at the lower.

CLIFF GLACIER NORTHWEST OF SODA SPRINGS.

About 2 miles northwest of Soda Springs there is evidence of the former existence of a small cliff glacier of the last epoch. This glacier had its origin at about 11,900 feet and sent a narrow tongue of ice three-fourths of a mile down the valley. At its lower end a plug of drift lies across the valley.

EVERGREEN LAKES SYSTEM.

The ice of this system had the characteristics of a small ice cap rather than a valley glacier, for it occupied an area on the mountain side 2 to 4 miles wide, and was not limited to any single valley,[a] but moved down the mountain in a broad sheet, covering ridges and valleys. Nevertheless, it had several distinct sources.

SOURCES OF THE ICE.

Source 1 has very steep walls at its head, but the rock is almost everywhere covered with postglacial talus. Though moutonné outcrops appear, the rock surface is generally concealed by drift. The cirque is broadly U-shaped, and the glaciation must have been strong to give it its present shape. The side walls of the cirque head are steep, and contain little loose material. All shoulders and projections of rock have been well rounded, although few of the glacially smoothed surfaces have withstood the postglacial weathering. The ice limit is not particularly well defined, but can be approximately determined by the absence of rough outcrops and the somewhat steeper slopes of the walls below the upper ice limit.

Source 2 is a broadly U-shaped, shallow valley. The slopes are for the most part covered with talus, and little bare rock appears at the

[a] The topography as shown on the map differs essentially from the actual topography of the region. The stream which the maps shows as running into the Evergreen Lakes from cirque 4 is not in existence, and the stream which drains valley 4 is a tributary of the main stream in the valley of cirque 1. At the point where a steep ridge is shown to separate the valleys of these two cirques there is no ridge.

surface. The glaciation here was comparatively feeble, for the valley is free from heavy drift for only a short distance from the head. Along the ridge which separates this cirque from source 1 the rock wall is very steep. Below this cliff long tongues of talus run out into the valley. The talus blocks are angular and large, blocks 8 to 10 feet in diameter being common. These tongues of talus have probably been carried to their present position by landslides or by avalanches from the steep slopes above. At the point where this cirque joins the main valley there is a considerable plug of heavy drift across its lower end. This has the typical terminal-moraine topography, and the kettles often contain small ponds. Behind the drift dam is a small lake surrounded by a considerable flat. This drift plug was deposited when the ice in this cirque had retreated and severed its connection with the main ice lobe, the drift being dumped just outside the edge of the larger glacier.

Between sources 2 and 3 there is an interlobate-moraine ridge one-half mile long, which lies on the top of the dividing rock ridge. It has a crest about 60 feet high at the upper end, and gradually becomes lower down the valley, where it loses its ridge form.

Source 3 gives the impression of having been only feebly glaciated. The considerable thickness which the ice had here may have been due to the fact that the ice of the main valley stood high across the outlet of this cirque, rather than to any great thickness of moving ice in the cirque itself. The valley is not deeply excavated, and the walls and bottom are not severely eroded. Heaps of talus cover most of the rock surface.

About a mile below the head of this cirque, on its east side, a lateral-moraine ridge swings out from the rock nose and lies along the valley side. At its upper end it has an outer slope 80 feet high. The material is old in appearance, owing to the fact that the cirque above was not deeply eroded. Bowlders 4 feet in diameter are uncommon. This lateral moraine is composed of a number of minor ridges or benches, all running parallel to the outer edge of the moraine. Near its upper end it crosses and obstructs a large draw in which a considerable flat has since developed. The drift dam stands up above this flat from 5 to 30 feet in a well-defined ridge. Below this flat the lateral moraine lies along the rock valley wall, with only a low ridge crest, for about a mile, and then descends to the valley floor and flattens out to merge into the terminal moraine.

Source 4 is broad, but was not deeply eroded. It slopes with a somewhat continuous gradient almost up to the head, instead of having steep head walls and a low gradient for the valley floor. Here the erosive action of the ice was distributed over a wide floor, and the glacial deepening was consequently much less than it would have been if the ice had been concentrated in a narrow valley bottom. The

walls and bottom of this cirque basin are completely covered with talus, which everywhere obscures the rock below.

On the south side, just below the peak of Mount Massive, the topography of the talus is due to avalanches or landslides. The talus lies in curved ridges, the convex side toward the cirque wall. The ice limit on these talus-covered walls can be only approximately mapped, as there is no difference in the appearance of the walls below and above the line to which the ice must have filled the valley. Farther down the valley the ice is spread out on the flank of the mountain and was not confined to any single drainage line. Here the erosive power of the ice was not great and a body of heavy drift lies far up the mountain side.

The south wall of the cirque is steep and no heavy drift lies upon it, but the drift covers the valley floor to within little more than a mile of the mountain peaks. This heavy drift has often a humpty-dumpty topography, and many little ponds are scattered over it. Large fresh bowlders lie scattered everywhere, and the drift has considerable relief, indicating some thickness.

From the point where the ice limit crosses the ridge between sources 1 and 4 a recessional moraine crosses the valley in a great curve to the southeast. This moraine has a low but well-defined ridge and must have been made late in the history of the glacier.

Source 5 heads in the east side of Mount Massive and its top reaches an elevation of 13,700 feet. Notwithstanding the altitude of its head and the absence of close competition from parallel valleys, the glaciation was not at all strong. The cirque is narrow and not conspicuously U-shaped, and the upper limit of glaciation is nowhere more than 300 or 400 feet above the valley bottom. The walls at the very head are steep, but no glacially smoothed outcrops occur. The ice limit in the upper end could be determined only from the shape of the valley. The valley floor is covered with talus and bowlders to its upper end. Hard, fresh bowlders are rather uncommon in this valley, as is often the case where the ice action was of only moderate intensity.

HEAVY-DRIFT AREA.

In the lower part of this valley there is everywhere a considerable quantity of drift, but the topography is largely that of the underlying rock, and few kettles and hummocks appear. Between the Evergreen Lakes and the upper edge of the heavy-drift area there is a great stretch of mountain side which is covered deeply with drift. This drift sometimes occurs as distinct ridges, but over most of the area there is a confused succession of hummocks and kettle ponds. Bowlders, often 15 to 20 feet in diameter, lie scattered over the irregular surface, which shows almost no trace of postglacial erosion.

A cut of a few feet through the loose drift would drain many of these ponds, yet even this much erosion has rarely taken place. Even the surfaces of many of the bowlders are free from lichens and moss. The new appearance of the material of this drift is in striking contrast to the material of the Lake Fork moraines. (See pp. 43–44.)

TERMINAL MORAINE.

The terminal moraine rises sharply from the plain just east of the Evergreen Lakes. It has no uniform crest line, but rises in a series of irregular hummocks. The Evergreen Lakes themselves are kettles filled with water, and the whole area around them is of the strongest terminal-moraine type. South of the Evergreen Lakes the outer edge of the terminal moraine swings back to the southwest as far as the base of the mountains. Here it swings south at a sharp angle, where the ice from source 5 reached just below the base of the mountains. South of source 5 the ice limit can be determined only by the presence of scattered bowlders and the lack of unglaciated outcrops back to the point where it lies along the talus-covered slopes of the valley wall.

SYSTEM NORTH OF HALF MOON CREEK.

Between source 5 of the Evergreen Lakes system and Half Moon Creek there was a small body of glacier ice which occupied the parallel valleys of two small streams. In the northernmost of these valleys the ice movement started at an elevation of 12,000 feet, but in the valley south of this it had an altitude of 12,500 feet. Both of these valleys are broad and not very steep, so the ice action was not strong except at the very heads. Neither cirque is deeply eroded, and drift and talus cover the valley floors throughout their entire length.

On the south side of this system the ice edge lay along the rock wall for most of its length. Toward its lower end a lateral moraine ridge 20 to 30 feet high was formed. This swings away from the valley side in a northeast direction and grades into the terminal moraine. The terminal moraine of the south valley was built on the lower edge of the mountain slope, its lower edge reaching almost to the plain beyond. From this plain the drift rises steeply to a bench which corresponds to the crest, and then slopes up toward the mountains with a more gradual slope. In the northernmost valley the terminal moraine is not so well marked. It crosses a rock ridge in a reentrant loop at about the 11,100-foot level and then runs north with a distinct crest. This crest then curves to the west and the ice limit lay along the side of the rock ridge which separated it from the Evergreen Lakes system. Within, the terminal moraine is of slight relief and not very irregular. In the south valley a recessional moraine ridge 15 to 30 feet high lies within and parallel to the outer

ridge, one-fourth mile above it. Although the drift everywhere covers the rock, it is probably rather thin over most of the area, and its topography is due, in its larger features, to the underlying rock.

HALF MOON CREEK SYSTEM.

This system occupied the valley of Half Moon Creek from its head to a point well out upon the piedmont plain. It headed in three fan-shaped cirques which brought ice from the west of the high ridge of which Mounts Massive and Elbert are the peaks, and received no ice at all from the east slopes of these ridges.

SOURCES OF THE ICE.

Source 1 took the ice from the west slope of the Mount Massive ridge and from the east slope of the next ridge to the west. Its fan-shaped valley consists of the valleys of eight minor streams, which join at the apex of the fan. The rock of the walls of this cirque is a banded gneiss. The walls are very steep, and are almost everywhere covered by great accumulations of talus, with slopes of 35° to 40°. The abundance of talus here is due to the easy weathering of the rock. This would also account for the absence of smoothed and rounded outcrops. The talus-covered walls show no distinct marks of glaciation and the ice limit could be determined only approximately. The bottom of the valley is free from loose material, and the signs of glacial action are here well preserved, for the rock is everywhere rounded and smoothed. The ice and snow, lying longest in the cirque bottom, would protect it from weathering for some time after the walls had been exposed. The basins of the three lakes in the north end of this cirque are in rock. From the highest of these lakes the valley floor descends in a series of steps, on which the lakes occur.

Directly north of the uppermost lake is a broad shallow area which is not glaciated but which shows evidences of glaciation. With this exception the head wall of this cirque ends at its upper edge in a series of sharp needles, where the ice from opposite sides of the ridge has excavated the cirque heads back to the divide, lowering the divide an unknown amount.

At the mouth of this fan-shaped cirque, at the point where it joins the main valley, lies a narrow deposit of heavy drift, occupying the valley bottom. This must have been left by the ice during its retreat, for this would naturally be the point of severest glaciation, as the narrow valley here greatly concentrated the ice from a wide head.

Source 2 has many of the characteristics of source 1 and is separated from it only by a narrow ridge. The rock valley wall on the north, however, is comparatively free from talus and shows the effect of ice erosion. The rock of this wall is banded gneiss, and while the

bands are much contorted they are somewhat persistent, and the general dip is about 20° to the northwest. The valley at the upper end is free from talus, and all projections of rock are moutonné. This source is divided into five minor subdivisions. Over the four to the west the ice was continuous and the ridges between are rounded and moutonné. The fifth valley, entering from the south, is separated from the others by a high, craggy ridge, over which the ice did not pass. At the lower end of it there is, as in source 1, a plug of heavy drift, which must have been left as a recessional moraine. This plug is about 200 feet high against the south valley wall, and slopes down to the valley floor on the north. It has an irregular surface containing a few shallow depressions and is strewn with bowlders.

Source 3 consists of the basin of Elbert Creek, in which the ice moved almost directly north to the main valley. At the lower end of this cirque the valley walls are glaciated only one-third of the way up the slope, so the valley could never have been nearly full of ice. Below the upper limit of the ice the ends of the spurs from the Mount Elbert ridge have been truncated and the valley is U-shaped. The walls of this valley, even where it has been glaciated, are weathered considerably, so that none of the original glaciated surfaces remains. The rock surface is everywhere covered with talus, and the shape of the valley gives the only clue to the height reached by the ice. Near the head of Elbert Creek the valley is somewhat broader and the head walls rise in a steep, unbroken slope to the crest of the ridge. This head wall is covered with talus, and the upper limit of the ice could be determined at points only.

The west wall of the cirque is broken into a number of minor valleys, and the upper limit of the ice is an irregular line much obscured by talus, but determinable at many points by rounded shoulders or truncated spurs. At the lower end of this cirque, as of heads 1 and 2, there is a drift plug in the valley. It dams up the mouth of the cirque to a considerable height, and the stream has a steep gradient on the outside of this plug.

MAIN VALLEY.

The main valley, below the junction of these three heads, has a broad U shape, but is not altogether free from loose material. Even in the light-drift area there is considerable drift in patches. On the north valley wall the upper limit of glaciation is very indistinct. On the south wall the glaciation was more intense and the ice was higher than on the north side. This may have been caused by the north wall receiving more heat from the sun and thus keeping the ice melted back. A series of truncated rock spurs gives a definite line to which the ice reached. In the main valley, below the junction of the three heads, the ice was from 600 to 800 feet deep, and to this height has

widened the valley and given it a U-shaped cross section. For the development of such a trough from the V shape, which the unglaciated valleys of this region have, the removal of a great quantity of material was necessary, and much of this material is now to be found in the moraines and terrace deposits.

MORAINES.

One mile southeast of the junction of Elbert and Half Moon creeks a distinct lateral-moraine ridge leaves the rock wall and runs parallel with the valley for about a mile, but with its crest 200 feet below the upper limit of the ice as it appears on the rock wall above. This is plainly a lateral moraine of a recessional stage of the glacier, and between this ridge and the stream the valley floor has a covering of heavy drift.

Three miles above the terminus of this system, on the north side of the valley, a great lateral-moraine ridge leaves the rock spur which forms the valley wall above it and continues for 3 miles to the northeast with an unbroken, evenly descending crest. The ridge at its highest point is 500 feet above Half Moon Creek, and on the outside is 150 feet above the plain. Bowlders are scattered over it, and upon its very crest are basins. This ridge becomes lower and lower downstream, and is only 20 to 30 feet high where the stream cuts through it.

The south lateral moraine is smaller than the ridge shown on the map. By aneroid its crest is 700 feet high on the stream side, though only 60 to 70 feet above the surface outside. The ridge is even crested and almost unbroken, and in places has an inner slope of 25°. A little below the place where this ridge leaves the valley wall a small stream has made a postglacial cut 15 or 20 feet deep in the side of the ridge and a shallow notch in the crest, which is otherwise unbroken.

At their lower ends these two great lateral moraines flatten out and converge, forming a belt of terminal moraine of slight relief. Some undrained depressions occur, but the glacier has left a smaller deposit of terminal moraine than would have been expected from a glacier of this size. The ice, by building up the great lateral-moraine ridges on either side, confined itself to a narrow valley, and the result was much the same as if the glacier had ended in a narrow canyon. The narrow depositing end of the glacier dumped its material in the narrow valley, and this material was carried away by the abundant glacial waters about as fast as it was deposited.

HEAVY DRIFT AND TERRACES.

The heavy drift, within the moraines, has a somewhat irregular topography. It is unevenly distributed, in some places filling the valley to a considerable depth, while at other places the stream has developed a good flat in the drift.

Locally, patches of stratified gravel make terraces, doubtless deposited in advance of the retreating ice edge as a valley train.

OLDER DRIFT.

Southeast of the south lateral moraine of this system, and bordering it, is an area of glacial drift left by the ice of the earlier epoch of glaciation. This drift has been cut by gullies into a number of spurs which slope from the new moraine ridge down toward the east. The material of these spurs is older than that of the new moraines, and its topography is certainly an erosion topography, valleys of considerable size having been cut into it. On its surface are bowlders up to 3 or 4 feet in diameter, some of which have smoothed, subangular surfaces which look extremely like those of glaciated stones. On some of these there are indefinite markings which look like striæ, but no unequivocal striæ were found. The topographic position of this material and its physical characteristics point strongly to its glacial origin.

HIGH TERRACES.

Below the area of older drift connected with the Half Moon Creek system of glaciation and extending eastward from it to Arkansas River is a fan-shaped area of high-terrace gravels. This fan is about as broad as it is long, and although it has been considerably cut by erosion, the remnants of the old summit lie in a common plane which has a slope upward toward the mountains of about 2° at the valley edge and about 3½° at the mountain edge. Few good sections in these terraces were found. The material, however, is gravel, the stones being sometimes almost a foot in diameter at the upper edge of the terrace, but grading down to cobbles and still smaller gravels at the lower edge. The gravels of this terrace are much older in appearance than the materials of the new drift. Few surface stones have withstood the weathering, and those that remain are often so decayed as to crumble beneath the hammer. So far as is known, these terraces are formed of loose, uncemented material. For the development of the plain of which they are remnants there must have been a great amount of detritus supplied to the streams. In following these terraces to their upper edge we get a clue as to the source of this material, for the terraces appear to be built out from the moraines of the older epoch of glaciation. During this epoch great quantities of material must have been supplied to the extraglacial streams. These streams, depositing their materials on the flat beyond the edges of the moraine, built up a great outwash plain, of which these terraces are the remnants. The terrace materials correspond closely in age and appearance with the older drift. In

degree of erosion, in oxidation of materials, and in the decay of the bowlders the two agree closely. Another fact which fits well with the theory of fluvial origin is that the slopes of these terraces are not always in the same direction, but the slope is everywhere toward the periphery of the alluvial fan. This would be very unusual if the deposits were laid down in a lake bed, but is the normal way in which the gravels from a fan-building stream are deposited. At the end of the earlier glacial period, when the streams ceased to build up their channels and began to cut away the deposits which they had already laid down, Half Moon Creek had its course along the northwest edge of its fan. Here it intrenched itself, and before the last ice advance had cut a broad flat into its old alluvial deposits. When the last glacier moved down the Half Moon Valley it was walled in on the east by this great gravel deposit and by the moraines of the older glacier, and was forced to turn to the north along the interglacial gorge which the stream had cut into the older moraines and the outwash plain.

LOW TERRACES.

In the valley of Half Moon Creek, beyond the terminal moraines of the last glacial epoch, are deposits of gravels which bear the same relations to the last moraines that the high terraces bear to the older moraines. These low terraces have their best development in the Half Moon Creek valley because it is here that interglacial erosion had made the greatest inroads into the high-terrace gravels and had developed a considerable flat. In this flat conditions were favorable for the deposition of the low-terrace gravels. These gravels form an alluvial fan of low slope, with the apex at the sag in the terminal moraine through which Half Moon Creek flows. From this cut the gravel deposits slope away from the moraines in a great cone, the average slope being $1\frac{1}{2}°$ to $2°$. The top of this terrace plain is some 200 feet below the level of the high terraces immediately south. In physical condition as well as in topographic position these gravels are related to the ice of the last epoch. The materials are not at all oxidized, and the surface shows little erosion.

The glacier waters of the last epoch, with their burden of sediment, poured from the gap in the moraine onto a comparatively flat plain, where the material was deposited, with the slopes of a low alluvial fan.

Since the retreat of the ice the stream, less heavily loaded than before, has begun to deepen its channel in the steeper portion of its course. It has now cut its bed some 20 feet into these gravels at the top of the slope, but at the lower edge the stream meanders along with its bed only 3 or 4 feet below the surface of the terraces.

CLIFF GLACIER SOUTH OF HALF MOON CREEK.

Between Half Moon and Lake creeks there was a small cliff glacier which headed on the northeast side of Mount Elbert. This glacier was about a mile long and one-third of a mile wide. Its erosion was feeble, as it only slightly modified the upper end of its valley. At its lower end is a terminal moraine of coarse, angular blocks. The ice from this glacier did not descend much below 11,000 feet during the last epoch of glaciation, though there is evidence that it descended considerably farther at some earlier stage.

LAKE CREEK SYSTEM.

This system lay in the valley of Lake Creek and the Twin Lakes. It was the largest and longest system west of Arkansas River, having an area of about 80 square miles and a length of about 20 miles. It was fed by about 20 tributary cirques, of which 10 are in the Leadville quadrangle. The ice supplied to this glacier came not only from the east-west valley of Lake Creek; the glacier head was west of the ridge that limited the Half Moon Glacier, and it received ice from the west side of this ridge. The cirques shown on the Leadville sheet are those which join the main east-west valley from the north and from the south.

SOURCES OF THE ICE.

Source 1 took the ice from the east and south slopes of Mount Elbert, where the ice at the head had an altitude of more than 13,000 feet. This source had two subheads, partly separated by a dividing ridge, but the valleys on either side of this ridge have much the same characteristics. They show much bare rock and have only small accumulations of talus. The rock outcrops, however, do not seem to be severely glaciated, but are often more or less angular. These exposed surfaces are very generally covered with mosses and vegetation, and this tends to weaken perhaps unduly the impression of any great severity of glacial erosion. The head walls rise steeply from the valleys with slopes of 25° to 30°. On the ridge between the two heads is a rock hill, which was glaciated all over, but it stands well up above its surroundings and must have been a nunatak at one stage of the glacier's history. Below the mouth of this cirque, beyond the point where the ice was constricted to a narrow neck, the glacier spread, some of it moving to the southeast and some pushing, in a comparatively thin sheet, eastward. This sheet deposited a thick layer of drift, masking the rock topography, and joined the ice in the main valley to the southeast.

Source 2 is a small cirque in which lay a cliff glacier. The supply of ice from this glacier must have been small, for the valley shows little evidence of glacial erosion. A drift plug fills the valley just above the point where the ice from source 1 crosses the valley mouth.

Source 3, often known as Monitor Gulch, is a fairly well-shaped cirque, but was not severely glaciated.[a] The walls and bottom of the cirque are covered with talus and residual material. No considerable areas of bare rock occur, and postglacial weathering has reduced all the outcrops to roughness. In earlier glacial times this glacier may have joined that in the Lake Creek valley, but during the last glacial epoch this cirque sent ice down only a short distance from the cirque head. Below the cirque valley head the gulch becomes narrow and V-shaped.

Source 4, sometimes called Echo Gulch, has much the same characteristics as source 3. It has a cirque at its head, but is V-shaped toward its mouth, and although its ice may have joined the Lake Creek Glacier in the earlier epoch of glaciation, it did not do so during the last epoch. The gulch is broken up by minor ridges into a number of subordinate valleys, so as to destroy the symmetry of the whole. The cirque floor has considerable loose material, and in places the glacial erosion has been so slight as to make the determination of the ice limit difficult.

Source 5, known as Hayden Gulch, is much like sources 3 and 4 in general features. Its U shape has not been well developed, except at the valley head, and the upper limit of glaciation is therefore often indistinct. All outcrops have been weathered to roughness, and this weathering has produced talus sufficient to cover most of the surface. At the point where this valley joins the main trough the evidence of glaciation is so slight that one might pass along the main valley without suspecting the existence of the cirque, although the ice from this valley joined the Lake Creek Glacier. The valley mouth is hanging.

Source 6, or La Plata Gulch, is much more perfectly developed than any of those on the north side of Lake Creek. It has a peculiar, spatulate shape, being very narrow and deep along its lower course, but having a wide head, with a rather flat floor. The head walls are steep and high, and the valley floor at the head has little loose material. Where the ice was restricted to a narrow neck between the cirque walls the glacial erosion was pronounced and the walls were severely glaciated. The rock at the sides and head weathers easily, and there are now considerable accumulations of talus. The ice from this cirque crossed the ridge to join that of source 7 at an elevation of about 12,000 feet.

Source 7, known as La Plata Basin, is a hanging cirque. It has not the typical cirque shape, for it lacks the characteristic flat bottom and steep head and side walls. The ice action here was relatively

[a] Monitor Gulch is the gulch next east of Echo Gulch. The Leadville sheet (base of Pl. I) shows this area so inaccurately that source 3 on the map occupies only approximately the actual position of Monitor Gulch.

weak and did not excavate the valley to so great an extent as it did in the cirques to the east and west. The cirque contains considerable talus, which covers most of the rock of the walls.

Source 8, or Crystal Lake Gulch, is one of the most perfectly developed cirques of the whole area. Its broad, flat valley and steep head and side walls are typical of intensely glaciated valleys. These walls rise almost perpendicularly for 1,500 feet above the valley floor. Everywhere they are smoothed and rounded, although the polished and striated surfaces have rarely been preserved. The valley is almost free from talus, although some has accumulated at the base of the cliffs. In the upper end of this cirque the rock floor is often bare, and its surface is everywhere rounded and smoothed. In basins scooped out of the solid bed rock are several small lakes.

Source 9, or Willis Gulch, has a wide, well-developed upper end, but narrows noticeably toward its junction with cirque 10. This narrowing is probably due to the increased gradient of the valley at this place, the ice moving more rapidly, and consequently failing to fill the valley to so great a depth as in the upper, more sluggish portion.

The upper limit of ice in this cirque could not be determined definitely. Everywhere the valley walls are covered with great quantities of talus, which obscure the rock in situ. This is especially true of the southeast side, where the talus, sliding down into the valley from the cliff above, has accumulated in enormous heaps, which sometimes show a crescentic, landslide ridge form.

Very few outcrops of rock occur in the valley, which is everywhere covered by talus. This talus has sometimes formed into huge "talus glaciers," which have advanced out into the valley from the walls on either side. There is now no lake at the place where one is shown on the map, but about a mile above this place there are two shallow lakes where the stream has been dammed up by rock slides. In the valley bottom at the lower end of the cirque is a body of heavy drift, covering the floor and extending up almost a mile beyond the point where source 10 joins it. This heavy drift varies in thickness and its surface has many bowlders.

Source 10, or Little Willis Gulch, is narrow and has not been greatly deepened by the erosion of the ice. It is shallow and not well U-shaped, and could not have been subjected to very vigorous glaciation. The walls and bottom are everywhere talus covered, and the upper limit of the ice could be determined only approximately.

Source 11, or Boswell Gulch, is a wide, shallow basin from which some ice moved to join the main glacier, but it is not at all a characteristic cirque. The walls on the west and south are fairly steep, but not very high, while on the east the valley was deepened but little by the ice. The head of the valley is only a little above the altitude

A. LAKE CREEK GORGE AND MONITOR ROCK.

Photograph by Westgate.

B. TRUNCATED SPUR, SHOWING TRIANGULAR FACET, BETWEEN CRYSTAL LAKE AND WILLIS GULCHES.

Photograph by Westgate.

which was necessary for the formation of a glacier, so that the ice action was naturally feeble. Few rock outcrops occur in the valley bottom, and the impression given is of very mild glaciation. Heavy drift extends some distance up this area on its eastern edge, where the drift takes on the form of a low topographic ridge for about three-quarters of a mile.

MAIN VALLEY.

The main valley of Lake Creek, above the mouth of the rock gorge, is typical of a severely glaciated mountain valley. In this great gorge the ice was about 2,000 feet deep. The movement of this enormous body of ice, shod with an abundance of rock fragments, altered fundamentally the preglacial shape of this gorge. The valley cross section was changed from a V to a broad U shape. All projecting spurs from the valley walls to the north and south were truncated, and the triangular facets which these truncated ridges now present afford an indication of the extent of the glacial erosion (Pl. III, *B*). At the mouth of Monitor Gulch, or source 3, there is a great projection of rock from the valley wall which stands out prominently into the valley (Pl. III, *A*). This projection is known as Monitor Rock. Although it stood up nearly to the upper surface of the glacier, it shows polished surfaces and striæ to its top. This rock is one of the few notable breaks in the otherwise perfectly developed U shape of the valley, and owes its preservation to its hardness and its freedom from joints. From the mouth of the Lake Creek Gorge to the edge of the Leadville quadrangle the valley bottom is free from drift, and the rock outcropping in the valley bottom is rounded and moutonné.

HEAVY-DRIFT AREA.

The upper limit of the heavy-drift area of this system runs from the mouth of cirque 1 in a southerly direction and includes all of this system to the east of this line except the upper part of sources 10 and 11. In the western part of this area the heavy drift lies as a thin mask over the rock ridge, and the large features of the topography are doubtless due to the underlying rock. Occasional kettles occur, and everywhere over the surface are scattered numerous bowlders. Of these bowlders the most conspicuous are granites composed of great crystals of feldspar in a gray matrix. The bowlders came from the Sawatch Range, and the parent rock occurs in this range only in the valleys of Lake and Clear creeks. In the eastern part of the area of heavy drift the drift takes on a huge ridge form which rises in places 400 feet above the lakes, and this ridge seems to consist wholly of drift. It has a well-defined, sharp crest for most of its length, the crest being near the outer limit of the new drift, which is

built up against older drift. On the outside this crest stands 60 to 80 feet above the old drift and the high terraces. North of the lower lake the inner slope of the lateral moraine shows benches, one above the other, which probably mark halts in the ice during its retreat. In one place four distinct levels are shown.

The lateral-moraine ridge swings in a broad curve to the southeast with a descending crest, which ends rather abruptly. The ice at its maximum extension reached beyond the end of this great lateral moraine and pushed east to Arkansas River, leaving a terminal moraine of slight relief.

On the south side of the valley the heavy drift lies against the valley wall without ridge forms down to the point where the ice edge left the rock wall. Below this point the moraine is a ridge 300 feet above the lake. This ridge swings to the northeast, gradually becoming lower and lower toward the river. It has a rather notched, uneven crest and on the outside stands about 75 to 100 feet above the terraces. Outside of the main ridge are low ridges parallel with it, showing that at some time the ice of the last epoch extended farther south than it did when the larger ridge was built.

The character of the drift on the south side of the valley is much the same as it is throughout the whole heavy-drift area. The surface is everywhere strewn with bowlders ranging up to 15 feet in diameter.

TWIN LAKES.

The glaciation of the last epoch is directly responsible for the formation of the basins which are now occupied by the Twin Lakes. At the time of the farthest advance of the ice in this valley the glacier reached down to Arkansas River and built up the great lateral moraines on either side of its valley. When conditions changed and the ice began to recede its edge did not move backward at a steady, uniform rate, but the retreat consisted of an alternation of recessions and halts. At the halting places the ice edge remained long enough to build crescentic terminal-moraine ridges across its valley. The most conspicuous of these ridges is that which lies to the east of the lower lake, and it is this ridge which has dammed up the basin now occupied by this lake. A second noticeable recessional-moraine ridge is that which separates the two lakes at Interlaken. This was formed in the same way as the ridge below the lower lake, but at a later stage in the retreat of the ice. The lower lake existed while the site of the upper was still covered by the glacier. The upper lake had formerly almost as great an area as the lower, but subsequent silting has reduced its area by more than half and formed an extensive meadow above it.

GLACIAL EROSION.

The valley and tributaries of Lake Creek offer excellent opportunities for the study of glacial erosion and the relations of glaciated tributary valleys to the main valley. The exceptional development of these features has been recognized. L. G. Westgate[a] has given a valuable contribution to the study of glacial erosion in mountain valleys, based upon his studies of this valley and its tributaries, and W. M. Davis[b] has contributed two papers on his observations in this region.

As stated on page 11 the amount of topographic unconformity which a tributary valley has with its main valley is a fair estimate of the amount of glacial deepening which the latter has suffered. This process of deepening of the main valley and leaving the tributaries in unconformity with it is beautifully illustrated by the Lake Creek trough and its tributaries. These features are embodied diagrammatically in figure 5. The trough of Lake Creek above the Twin Lakes is

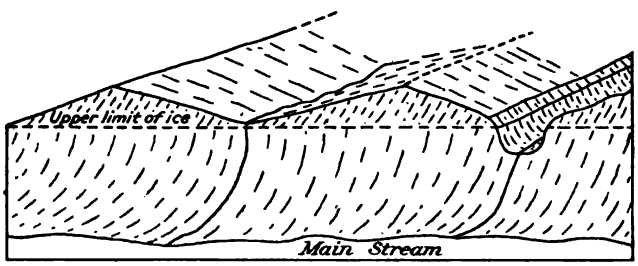


FIGURE 5.—Diagram showing glaciated valley and its relations to a glaciated and an unglaciated tributary. (After Westgate.)

a type of a severely glaciated valley. In cross section it is broadly U-shaped, the walls rising steeply to the line that the ice reached, which is as much as 1,600 feet above the stream. The erosion of the ice in this valley has in most instances entirely truncated the ends of the rock spurs between the tributary gulches (fig. 5). On the north side, on the lower slopes of the Mount Elbert ridge, there are a number of spurs which although rounded and much reduced still project somewhat into the troughlike valley. The fact that they were not entirely removed may be attributed to the superior resisting powers of the rock at these places, perhaps because of the absence of pronounced joints, without which glacial plucking is reduced to a minimum. That glacial plucking was important in the deepening and widening of this valley is shown by the characteristic shape of the rock knobs and moutonnées. The stoss, or upstream, side has usually a gentle

[a] Jour. Geology, vol. 13, 1905, pp. 285–312.

[b] Bull. Mus. Comp. Zool., vol. 49 (Geol. series, vol. 8, No. 1), 1905, pp. 1–11; Appalachia, vol. 10 (No. 4), 1904, pp. 392–404.

slope, while the lee, or downstream, side commonly shows a steplike form where the angular joint blocks have been plucked out (p. 12).

Of all the tributary valleys of this system Crystal Lake Gulch, or source 8, shows best the relations of a glaciated hanging valley to the main gulch. The collecting field for this tributary comprised the slopes of high north-south ridges, of which the highest point, La Plata Peak, reaches an altitude of more than 14,300 feet. With their altitude and favorable north exposure these ridges supplied ice for a strong glacier in this gulch, which now shows a marked U-trough development. At its junction with the Lake Creek valley the mouth of this gulch hangs 800 feet above Lake Creek. The postglacial erosion of Crystal Lake Creek has cut only a shallow notch in the bottom of the hanging U. On either side of the mouth of Crystal Lake Gulch the ends of the rock ridges have been sharply truncated, and above the upper limit of the ice they show triangular facets, due to glacial undercutting (fig. 5). A diagrammatic cross section of the trough of Lake Creek shows in characteristically developed localities (see fig. 6)

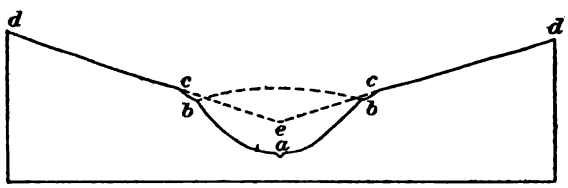


FIGURE 6.—Diagrammatic cross section of trough of Lake Creek. *d, e, d,* Preglacial profile of valley; *b, a, b,* area which suffered from direct glacial erosion; *b, c,* area of indirect glacial erosion by glacial undercutting; *c, b, a, b, c, e,* cross section of material removed, directly and indirectly, by glacial erosion. Horizontal and vertical scale, 1 inch=1 mile.

a U-shaped trough, with steep wall to the upper limit of glaciation (*b, a, b*). Above this the rock slopes are still steep, owing to glacial sapping, but less steep than below (*b, c*). Above the slope steepened by undercutting is the still more gentle slope of the unglaciated, normally developed mountain ridge (*c, d*). *b, b* shows the probable shape of the ice surface at its maximum. *e* is the preglacial position of Lake Creek, and *e a* shows the glacial deepening of the valley. *c, e, c, a, c* is the cross section of the mass of rock removed by glacial erosion.

It is not possible to reconstruct accurately the shape of the preglacial valley of Lake Creek from the unglaciated slopes above. However, estimates[a] of the amount of glacial deepening that are well within the limits of probability may be made from the relation of the hanging valleys to the main stream. Figure 7 shows a profile of Crystal Lake Gulch (source 8) and a cross section of the Lake Creek valley, taken from field sketches, photographs, and aneroid

[a] The reasons why such calculations are subject to error have been given on page 12.

measurements. The mouth of this tributary hangs 800 feet above Lake Creek. If we assume that the glacial erosion in the tributary gulch did not lower its valley floor at all, then by continuing the profile *a*, *b* to *c* we have the point at which the preglacial tributary

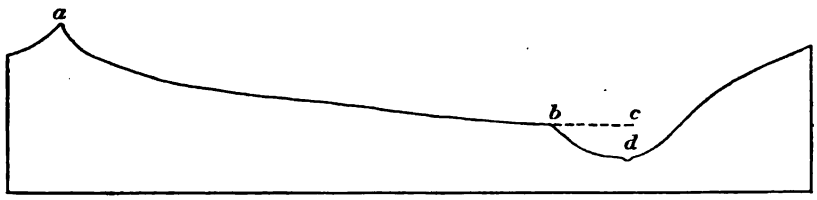


FIGURE 7.—Longitudinal section of Crystal Lake Gulch and cross section of Lake Creek valley. *b*, *c*, Extension of profile *a*, *b* to center of valley; *c*, *d*, glacial deepening of Lake Creek valley if mouth of tributary at *b* was not lowered any by glacial erosion.

would have joined Lake Creek with topographic conformity. *c*, *d* gives the amount of glacial deepening of the Lake Creek valley.

If we assume that the glacial erosion in gulch *a*, *b* lowered the valley bottom 100 feet, we need to add 100 feet to the glacial deepening of the main trough. (See fig. 8.) This estimate is probably conservative, for the smoothed, rounded floor of the tributary valley

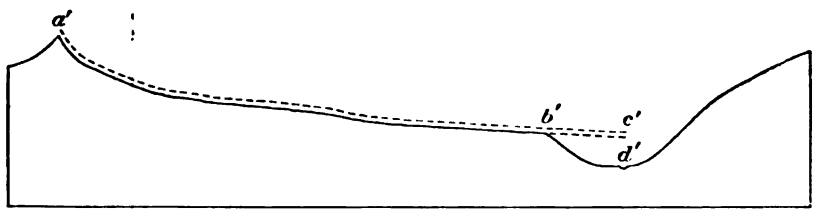


FIGURE 8.—Same section as figure 7. *a'*, *b'*, *c'*, Preglacial valley of tributary stream. Assuming that glacial erosion in tributary valley has lowered valley floor 100 feet, the preglacial mouth of the tributary would have been at *c'*, and *c'*, *d'* would be the glacial deepening in the main valley. Horizontal scale, 1 inch=one-half mile. Vertical scale, 1 inch=one-fourth mile.

shows that the glacial erosion of the rock at this place was a considerable factor.

OLDER DRIFT.

North of the north lateral moraine of this system there is an area of drift of the earlier epoch of glaciation. It is a narrow belt just beyond the outer edge of the new moraine ridge, its length being about 3 miles and its width nowhere more than a few hundred yards. Its topography gives no indications of undrained hollows or hummocks, although at one place it has the form of a low ridge parallel with the outer edge of the new moraine ridge. At the surface are occasional bowlders up to 4 feet in diameter, all deeply weathered and partly buried in the soil. Few sections were available, but one 30 feet deep showed a bowlder clay in which the bowl-

ders were all so decayed as to be readily cut by pick and shovel. The materials were the same as those in the new drift, only more weathered and rotten.

HIGH TERRACES.

Northeast and east of the Twin Lakes moraines there is a set of high terraces which bear the same relations to the older drift of this system of glaciation as the terraces below the Half Moon Creek system bear to the older moraines at that place. These terraces, although much more restricted in area, appear even at first glance to correspond to the terraces a few miles north. On closer inspection the similarity is even more striking. The two groups are obviously in the same stage of erosion. In the size and the weathered and oxidized condition of the gravels they are alike, and the pebbles differ in lithological characters only as would be expected, coming as they do in part from different localities. But the most striking fact bearing on the origin of these terraces is that they, too, occur just outside of older drift, as if built out from it, with only a slight topographic break between. This would seem to be strong evidence that the terraces were built at the same time as the moraines, and as outwash from them.

Between the south lateral moraine of the Twin Lakes system and Cache Creek there is an area—about 4 square miles—of terrace gravels not so high or so striking as those farther north, but probably of about the same age, as is shown by their topography and by the condition of their materials. An excellent section is offered at the placer mines along Cache Creek. About one-half mile west of Granite is a 60-foot section of gravels lying on a granite base. These gravels are mostly under cobble size, though some have a diameter of 4 feet. These materials are not everywhere distinctly stratified, but they are fairly well rounded. Lenses of sand are interstratified with the imperfectly assorted gravels. The materials have not been much oxidized, but most of the pebbles are much decayed, and porphyries of the sort which in the new drift hold striæ are here falling to pieces. The rock surface upon which these gravels lie is deeply decayed and can often be scraped up with a shovel and washed with the other materials. The rock surface dips to the west, suggesting that the main stream of the valley was once considerably west of its present position (fig. 1).

These terraces were built in much the same way as those farther north. The valleys in the mountains to the west were unglaciated, but their streams were probably stimulated to greater cutting and transporting by the abundant waters from the melting snows, and so aided the extra-glacial streams in aggrading this flat. These streams are still building up their alluvial fans on top of the terraces, and the

process of fan building may have been somewhat continuous since the earlier glacial epoch (fig. 9).

The plain of this set of terraces is considerably below the level of the high terraces to the north and south. At its eastern edge the plain is broken by a number of gullies which have worked back from Arkansas River and cut deep gulches into the gravel plain. Toward the mountains this plain is unbroken, and the flat-topped ridges between the gulches on the east edge of the area correspond in height so perfectly with one another that there can be little doubt as to the former flat, unbroken character of this area from the Twin Lakes moraine to Cache Creek. Westgate[a] states that these terraces are the erosive remnants of a set of high terraces which were originally in the same plane as the other high terraces to the north and south. If such were the case, it seems improbable that we should get such flat-topped ridges corresponding exactly with one another in level, unless the whole area had been peneplaned in interglacial times, and this seems almost impossible with gravels of such recent origin. The gravels which Westgate mentions, above the level of these terraces, might have come from the slopes east of the Arkansas Valley before the river cut its postglacial channel into the gravel deposits.

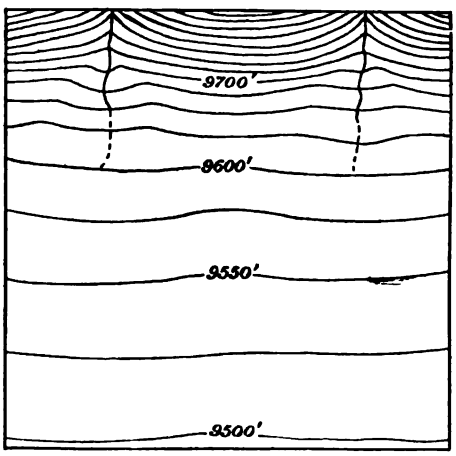


FIGURE 9.—Sketch map of an area, one-half mile square, showing relations of terraces between Lake and Cache creeks to mountain slope and to drainage lines.

LOW TERRACES.

Along the valley of the Arkansas below the Twin Lakes moraines there are a number of low-terrace remnants, all having about the same height above the river and occurring on both sides of it for 4 or 5 miles below the outlet of Lake Creek. These terraces all stand 10 to 30 feet above the river and 100 to 200 feet below the high-terrace level, and are composed of fresh, unoxidized gravels of apparently the same age as the late drift. Although the river has removed all but small patches of these terraces, they are evidently young, for gullies have not begun to work back into them. They were deposited during the last glacial epoch as a valley train, and later, when the river was not overloaded, it cut into the valley train it had built.

[a] Jour. Geology, vol. 13, 1905, p. 298.

CLEAR CREEK SYSTEM.

The basin of Clear Creek lies for the most part outside of the Leadville quadrangle, but the lower moraines of the system are within its boundaries. The total area covered by the ice is not known, but the system would certainly be classed with the larger ones of this range. The three sources belonging to this system that are in the Leadville quadrangle are not of the same type as the cirques farther southwest, but are only moderately glaciated, owing, perhaps, to their limited area and to southern exposure. The valleys are not deeply eroded by glaciation, and accumulations of talus have entirely obscured any signs of glaciation on the wall rocks. Their form gives some clue to the height which the ice reached. Beyond the limits of this quadrangle there are in this system several beautifully developed cirques, where the glacial erosion was more effective.

The main valley down to the point where the heavy-drift area begins is strongly glaciated. It had a well-developed U shape and all projecting spurs have been truncated. The easily weathered rock does not retain striæ on exposed surfaces.

Beyond the rock walls of the valley the glacier built up a pair of very perfect lateral moraines. These moraines are almost parallel and have even, unbroken crests which stand 700 feet above the stream at their upper ends. The inner slopes are often as steep as the material will lie, and slumping has notched the north lateral moraine in one place.

Between the two lateral moraines the valley is broad and is occupied for more than 2 miles by a flat, probably an old lake bed formed behind the terminal-moraine dam. At their lower ends these two lateral moraines flatten out and merge into a broad, low terminal moraine which reaches to and crosses the present bed of the Arkansas. Here the river occupies a new channel, and was pushed out to its present channel by the edge of the ice advancing from the valley of Clear Creek.

North of the Clear Creek north lateral moraine is a considerable patch of older drift, as shown on the map. This area is, for the most part, heavily timbered, but certainly patches of older drift occur in it. This drift has in general the same characteristics it shows in the other areas already mentioned. Weathered bowlders lie scattered about over a surface from which erosion has removed all traces of kettles or hummocks. The materials are all oxidized, and many of the bowlders are deeply decayed and falling to pieces. At one place in this area the older drift shows to some extent a lateral-moraine ridge form just outside of the new lateral moraine. This ridge is only about 30 feet high, and the slopes have an angle of 10° to 12°.

Between it and the ridge of the new lateral moraine there is a kettle, but no kettles occur in the older drift itself.

One mile west of Granite, on the south side of Cache Creek, there is a patch of terrace material, sloping north and northeast, which is notably higher than the terraces just north of Cache Creek. The materials in this area are about the same as those north of Cache Creek. Bowlders 2½ feet in diameter were seen at one section, but all were so rotten that they could be cut with pick and spade. Its topography is comparable with that of the other high terraces. At its upper end this area grades into a deposit of older drift and therefore can be definitely classed with the other terraces which are built outside of patches of older drift.

SYSTEM OF EAST FORK OF THE ARKANSAS.

East Fork of Arkansas River was occupied by a glacier for the upper 15 miles of its course. This glacier had an area of 20 square miles and was a typical mountain glacier, the ice body in the main valley being fed by the ice from 10 tributary valleys.

SOURCES OF THE ICE.

Buckeye Gulch.—In ascending the valley of East Fork the first of these tributary cirques that one reaches is Buckeye Gulch. The valley running south from Buckeye Peak has a cirque development, its head walls rising steeply for 500 feet above the valley floor. The valley floor is covered with loose material into which the stream has cut a gorge about 30 feet deep. At its head the valley is U-shaped, but farther down it becomes V-shaped, and the side walls are covered with heavy drift for 500 feet above the stream. The hill a mile south-southwest of Buckeye Peak was slightly cut into by the ice, but in the west fork of Buckeye Gulch the excavation was insignificant and the valley form was but little changed by the glacier.

The little cirque on the north side of Prospect Mountain is small and not deeply excavated. The head is U-shaped, but lower down the valley narrows and becomes V-shaped. There is little bare rock in this cirque, and the walls are everywhere covered with talus.

The little cirque east-northeast of Prospect Mountain is somewhat further developed than the cirque just mentioned. The head was more severely glaciated and the lower half is broader and shallower, but the walls and floor are covered with talus, so that little of the bed rock can be seen.

Birdseye Gulch.—This is a broad basin which was occupied by glacial ice. It is nowhere very deep, although the mountains to the east rise to elevations of more than 13,000 feet. The valley floor is completely covered with loose material, into which the stream has

cut a sharp though not very deep gorge. The upper limit of glaciation coincides rather closely with the timber line on the east wall, and the ice reached almost to the col on the south. In the whole of this valley the glacial erosion was slight, for in the wide, flat-floored valley the ice was not concentrated and was comparatively thin, so that the glacial gouging was correspondingly mild.

Valley southwest of Mount Arkansas.—This valley is short and steep and was rather strongly glaciated. It lacks the precipitous head walls so often seen in these cirques, but has a good U shape. In the head, above timber line, there is considerable postglacial talus, but below timber line the floor is covered with heavy drift.

Cirques east of Buckeye Peak.—The four small cirques on the east side of the Buckeye Peak ridge have much the same characteristics. The southernmost one is much the smallest and is the least perfectly developed. The three to the north all have rather steep head walls and broad, spatulate heads, though the ice never stood very deep in them. Toward the main valley these tributaries show more of a V-shaped cross section—a change due to the increased gradient of the valleys toward their junction with the main glacial trough. The increased slope of the floor caused the ice above it to move more rapidly and thus lessened the area of ice in a cross section at this point. This process, once initiated, would tend to augment itself, the more rapidly moving ice bringing about increased erosion of the valley bottom, and this, increasing the slope, would give increased velocity to the ice movement. The amount of deepening of the lower ends of these tributary valleys was limited by the height at which the ice stood in the main valley below.

Valley west of Chalk Mountain.—No ice originated in the valley of the stream which flows south along the west base of Chalk Mountain. The lake at the head of this stream was formed by the damming of the valley by talus blocks which came down from Chalk Mountain. At the point where this stream enters the main valley of East Fork of the Arkansas it flows over a cliff about 35 feet high, forming a beautiful waterfall.

Head of valley.—The head of the Arkansas Valley north of Mount Buckskin is a beautiful cirque, the east wall showing especially well the effects of glacial erosion. The whole cirque is excavated in the pre-Cambrian gneiss, and the amount of material removed by the ice was enormous (fig. 10). The upper 2½ miles of the valley are almost entirely free from drift, and although there is considerable postglacial talus at the base of the steep walls, it is insignificant in the wide valley. The ice limit along the mountains to the east is distinctly shown by the perpendicular outcrops of gneiss, above which the unglaciated slopes rise more gently to the peaks. Toward the head of

the cirque the east and south walls rise steeply to a row of serrate peaks, all of them well above 13,000 feet in height.

The west wall of the cirque is not so strongly eroded as the east wall, but is broken by minor valleys and spurs, and the talus accumulations are conspicuous. Throughout the head of this cirque the topography of the original stream-developed valleys has completely disappeared. Not only is there now no evidence of overlapping spurs and of tributary valleys, but these spurs, particularly on the east valley wall, have been so far truncated that the courses of the former tributary streams can not be located. At its deepest the ice in this valley was more than 1,000 feet thick, so that the extensive gouging and shaping of the valley is easily accounted for.

Fremont Pass.—Ice stood in East Fork of the Arkansas about 100 feet above the crest of the divide at Fremont Pass, so that some ice may have gone over into the Tenmile Valley. It is probable, however, that the ice from the cirque south of Bartlett Mountain stood almost

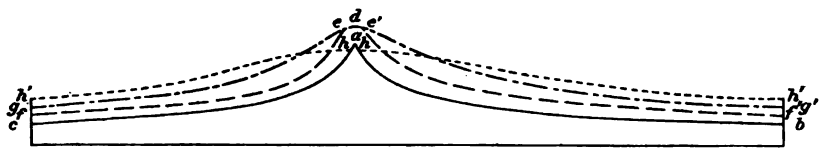


FIGURE 10.—Diagrammatic cross section of divide between head of East Fork of the Arkansas and Mosquito Gulch. *c, a, b,* The divide at the present time. On either side of *a* peaks rise to 13,700 feet, or to point *d*. *d, a,* Probable amount which this divide was lowered by glacial erosion; *g, d, g',* probable preglacial cross section of this divide; *f, c, e', f',* an intermediate stage in the glacial lowering of the divide; *h', h, h, h',* height to which the last glacier filled the present valleys. Horizontal scale, 1 inch=1 mile; vertical scale, 1 inch=one-half mile.

as high on the north side of the pass as the Arkansas ice did on the south side, so that the movement of ice over the pass was slight.

MAIN VALLEY.

From a point one-half mile above the loop in the upper railroad south of Fremont Pass to the lower edge of the terminal moraine the main valley floor has enough heavy drift to mask the topography of the underlying rock. With the exception of a few rock outcrops, the drift sheet in this area is continuous.

Along the river valley south of Chalk Mountain the stream has a cut 60 to 100 feet deep, and this cut exposes the Chalk Mountain rhyolite. A long ridge of this same rhyolite outcrops in a north-south direction near the union of East Fork of the Arkansas and the tributary from the west side of Chalk Mountain. On either side of the mouth of the glaciated valley southwest of Mount Arkansas there are knoblike outcrops of porphyry, and on the west side of the main valley are similar knobs. Between these the ice was somewhat constricted, but the valley widens both above and below them.

At many places in the main valley below Buckeye Gulch determination of the upper limit of the ice is difficult, but it can be located by an occasional bench or plug of drift across the mouth of some small side valley. Below this limit the easily weathered rock outcrops have in many places been reduced to roughness, though the general outlines of these outcrops are more rounded than those of the outcrops above the ice limit.

MORAINES.

No lateral moraines occur until the stream emerges from its rocky gorge. On the west slope of Prospect Mountain a good lateral moraine appears. This swings away from the mountain slope with a good ridge form, the outer slope being 50 to 75 feet high. This ridge curves to the west, and has an east-west course at the point where it is broken by a cut through which Evans Creek flows. West of this cut the moraine ridge continues to the west, and stands 50 feet higher than the lateral moraine on the north side of the Arkansas. One section afforded by a prospect hole showed the new drift to be more than 30 feet thick, overlying high-terrace gravels, so that this

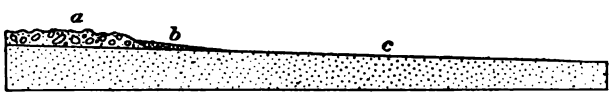
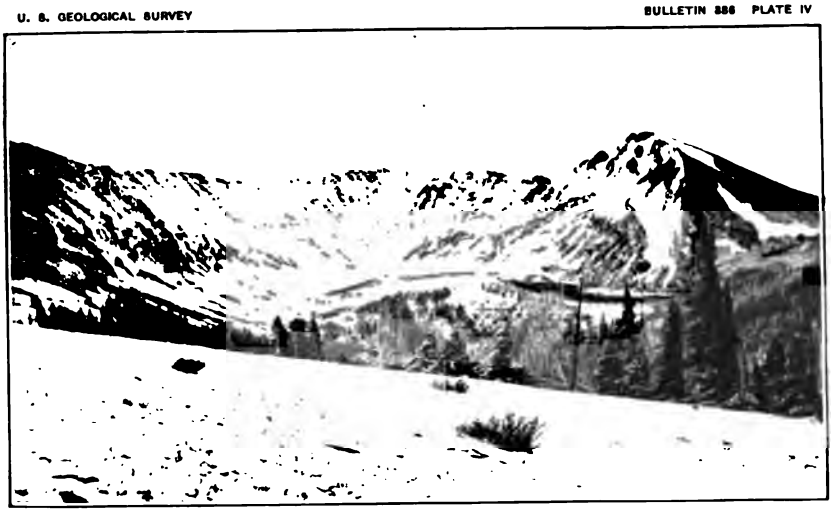


FIGURE 11.—Diagrammatic section south of terminal moraine of East Fork of the Arkansas. *a*, Moraines of last glacial age; *b*, outwash from last glacier; *c*, outwash gravels of older glacial age. Horizontal scale, 1 inch=one-third mile. Vertical scale, 1 inch=one-sixth mile.

moraine was at least partly built out upon the preexisting high terraces. To the west this moraine grades down, without topographic break, into the high terraces. No sharp line can be drawn between the two, the wash from the new moraine so overlying the high terraces that the transition is gradual (fig. 11).

The north lateral moraine is not so well developed as the south lateral. It is lower, and contains much less material. It lies as a bench along the side of Mount Zion, and its crest is considerably below the limit of glaciation as shown on the rock wall above it (Pl. IV, *B*). The small size of this moraine in comparison with the opposite one may result from the difference in exposure of the two sides of the valley. On the south side of this valley there is no rock valley wall, and the ice of the glacier, although indirectly exposed to the sun's rays, was not subjected to the reflected heat from a rock wall. On the north side the rocky slopes of Mount Zion rose above the edge of the glacier, and the heat reflected from this rock wall would have been influential in melting back the ice edge, and may have been in large part responsible for the difference in height of the moraines on the two sides of the valley.



A. HEAD OF CLINTON GULCH.

B. NORTH LATERAL MORAINE OF EAST FORK ARKANSAS SYSTEM OF GLACIERS.

No typical terminal [illegible] in this system as the dump from the end of the gla[illegible] rapidly away by the vigorous stream. This stream has [illegible] between the ends of the two laterals, and part of this is in the fractured rock.

AMOUNT OF GLACIAL EROSION.

On the northwest slope of Prospect Mountain there is a small hanging gulch tributary to East Fork of the Arkansas. During the last epoch of glaciation the mouth of this gulch was filled with drift, and into this drift the stream has developed a considerable postglacial cut. It is evident from the rock slopes of the sides of this draw that if all the drift were removed there would still be a considerable topographic unconformity between this gulch and the main valley. It is impossible to estimate closely the amount of this unconformity, but it must be from 100 to 200 feet; and these figures indicate roughly the amount of glacial deepening of the main valley at the mouth of this tributary.

HIGH TERRACES.

Beyond the lower end of this system of glaciation there are extensive high-terrace deposits, which are a part of the compound alluvial fan that, in interglacial times, extended from this stream south to Granite Gulch. These deposits are described in connection with the Iowa Gulch system of glaciation. (See pp. 93–94.)

LOW TERRACES.

Associated with the moraines of this system there are a number of remnants of a set of low terraces. The uppermost of these patches lies well within the glaciated area, and extends upstream more than 2 miles above the point that the ice reached at its maximum extension. The gravels form low benches on either side of the river flat, and are all that is left of a gravel plain which once extended across the valley and filled it to some depth. This valley train was built after the ice had retreated some distance, and is conclusive evidence that the building of valley-train deposits continued for some time after the ice had begun to retreat. Below the end of the moraines there is a narrow bench of these gravels on either side of the river. They were laid down in the interglacial gorge in the high terraces, and their surface stands about 100 feet below that of the adjacent high terraces. The materials of the low terraces are fresh and unoxidized, and the extent to which postglacial erosion has reduced them is due to their position in the valley bottom, where the stream cutting is most potent.

UPPER TENMILE CREEK SYSTEM.

Actually in contact with the system of East Fork of the Arkansas, but turning in the opposite direction, on the other side of the continental divide, was the system which occupied the upper end of the Tenmile Valley. This system headed in the little cirque south of Barlett Mountain, and its supply may have been somewhat augmented by ice coming over the pass from the East Fork system. The double cirque at the head of the Tenmile system is deeply excavated, and, although small, was the source of vigorous ice movement. Formed in the pre-Cambrian gneiss, this cirque has suffered severely from postglacial erosion, and the lower walls and the floor are covered with talus. The shape of the valley head, however, is that of a glacially shaped cirque.

Below the mouth of the cirque the floor is covered with heavy drift, and at the lower end of the system the drift takes on characteristic terminal-moraine topography, with hummocks and water-filled kettles. There is no sharp terminal-moraine ridge, and the drift merely flattens out and disappears to the north.

North of the terminal moraine of this system, 1 mile south of the village of Robinson, there is an area covered with drift of the older epoch of glaciation. Here scattered bowlders up to 3 feet in diameter lie beyond the edge of the last moraines. At one point east of the river this drift has some thickness, but it is mostly represented, in the area mapped as "older drift," by scattered bowlders, which are much more deeply weathered and oxidized than the materials of the last moraines.

LOWER TENMILE CREEK SYSTEM.

The lower Tenmile Creek system had its head in Clinton Gulch and occupied the Tenmile Valley from the mouth of Clinton Gulch to the hamlet of Wheeler. It was fed by seven tributary glaciers, the five larger ones joining the main valley from the east and the two smaller from the west. At its maximum the system had a length of 10 miles and an area of 12 square miles.

SOURCES OF THE ICE.

Clinton Gulch is the most important of the tributaries of the lower Tenmile Creek system. This gulch heads back to a mountain ridge which is nowhere less than 13,500 feet high, and received the ice from 2½ miles of the west slope of this ridge. As a result of its favorable topographic position this cirque received a large supply of

ice and was severely eroded. The head is broad, and the walls on all sides rise steeply to jagged peaks (Pl. IV, *A*). The upper limit of glaciation is marked by the perpendicular outcrops of the rock, above which the slope is not quite so steep. At the base of Bartlett Mountain the ice failed to erode as deeply on the west side of the cirque as on the east, and left a great broad rock bench, but except for this one break in its symmetry the cirque has the cross section of a typical glaciated valley.

On the southwest side of the gulch the ice pushed over the wall at an elevation of about 10,300 feet and spread down the west side of the ridge to the valley of the Tenmile. Over this ridge, however, there is only a thin coating of drift, as is shown by a number of prospect holes.

Once over the ridge, the ice was just strong enough to reach the valley bottom. The small hill one-fourth mile southeast of Kokomo was surrounded by the thin edge of the ice, but does not appear to have been covered by it, for while granitic and gneissic bowlders occur on the lower slopes of the hill, none occur on its top. From this hill the west limit of the ice runs north and reaches the west side of the Tenmile Valley just north of Kokomo. In the mouth of Clinton Gulch there is a considerable area covered with heavy drift. Here the drift covers the valley bottom and the walls for some distance on either side.

Mayflower Gulch heads in a well-developed cirque. The main cirque is divided into two parts by a low spur which has been almost removed by the glacial cutting from either side. The ice limit is sharply defined by the shape of the valley, the walls above being much more irregular and angular than the walls below the ice limit. The lower walls are almost completely covered with talus, but the flat valley bottom is free from loose materials.

The north fork of Mayflower Creek heads due east and has a small but well-developed cirque at its head. This cirque has much the same characteristics, on a smaller scale, as the main head. Like it, it has steep head walls with jagged peaks, and shows angular outcrops down to the ice limit, which is marked by a sharp topographic break, with perpendicular cliffs below. Below these cliffs there are large accumulations of talus, which obscure the lower walls and the valley floor.

Below the junction of these two cirques the glaciated area of the valley narrows rapidly and becomes more V-shaped, indicating that this was an area of dissipation of the glacial ice. The valley is free from heavy drift down to its junction with the Tenmile Valley.

Humbug Gulch cirque is of small area, and received most of its snow and ice from the subordinate lateral spurs of the mountain

mass. Two small fingerlike cirques head to the east, the larger one having cut deeply into the flank of Bald Mountain. In the cirques themselves the talus has covered much of the walls and floors, but farther down the valley the bare rock appears, rising in rude steps to the east. Toward its head the cirque is broadly U-shaped, but becomes narrower toward the west, and the ice seems to have had barely strength enough to push down to the main Tenmile Glacier. Its mouth is about 400 feet above the present Tenmile Creek, and is filled with a plug of heavy drift, through which Humbug Creek has cut a shallow postglacial channel.

Gulch 1, the next gulch north of Humbug Gulch, opens at its head into a broadly U-shaped valley with steep head walls. Great accumulations of talus cover the bottom and walls of the cirque and obscure the upper limit of glaciation. Its shape, however, shows that glacial erosion was vigorous at the upper end. Like Humbug and Mayflower gulches, it narrows toward its lower end, which hangs about 400 feet above Tenmile Creek. Across the lower end of the valley is a plug of heavy drift, through which the stream has a cut 30 to 50 feet deep.

Gulch 2, next north of 1, is much like 1 in general characters, although it is wider and deeper. The valley has two subordinate heads, both of which have steep head walls, with much talus below. Gulch 2 narrows and becomes V-shaped at its lower end. The glaciated area is almost a mile wide at its greatest width, but is scarcely one-fourth mile wide at its lower end, which hangs 400 feet above Tenmile Creek.

Tucker Gulch, just south of Jacque Peak, was glaciated, but not severely. The upper end of the gulch was not excavated to form a cirque, as it lacks the steep head and side walls. The upper limit of glaciation is not well defined, but the valley bottom in general has less talus than the higher slopes. The ice tongue in the lower end of this valley was only a few hundred yards wide and lay in a narrow V-shaped valley.

Copper Creek has a broadly U-shaped valley and steep head walls but talus and vegetation have now so covered the walls as to make it impossible to determine the upper limit of ice with accuracy. Like the neighboring gulches, this one narrows down greatly before joining the main valley, and the mouth is occupied by a plug of heavy drift.

HEAVY-DRIFT AREA.

In the main valley of the Tenmile, on the east side of the stream, there is a body of heavy drift which extends more or less continuously from the mouth of Clinton Gulch to the lower end of the area occupied by this system of glaciers. Below the mouths of the tributary cirques this drift has considerable thickness, cuts 30 to 50 feet deep, failing to expose the rock below. Here, too, the drift takes on a dis-

tinct drift topography, with irregular hummocks and kettles. This drift extends to the upper ice limit along the east valley wall and sometimes is disposed as a bench against the rock wall of the valley. On the east side of Copper Mountain the heavy drift does not reach to the upper limit of glaciation. Large outcrops of rock occur in the glaciated area, but the ice limit can be determined by an occasional pocket of drift or by bowlders.

In general the ice limit on the west side of the valley is 50 to 100 feet lower than on the east side. This is due to the greater supply of ice from the east and to the better exposure of the southeast-facing side of the valley to the sun, with resultant greater melting.

North of Copper Mountain the Tenmile Gorge received no more ice from its tributary gulches. The tributaries from the east are all hanging, and give an idea of the amount of glacial deepening which this valley has undergone. Below the mouth of Gulch 2 the glacier was decreasing in size, but continued down to Wheeler. There is no notable terminal-moraine deposit at this place, for the ice ended just within the mouth of the gorge, and the drift was carried away from the end of the glacier before it accumulated in any quantity.

AMOUNT OF GLACIAL EROSION.

A glance at any one of the strongly glaciated valleys of this region is enough to show that the amount of glacial erosion which it has suffered is very considerable. If this erosion had resulted merely in changing the valley cross section from a V shape to a U shape the amount of material removed would have been large, but added to this there was in most places a very considerable deepening. In the higher and more severely glaciated regions, where every valley of importance was occupied by a glacier, it is difficult to estimate the amount of glacial deepening, but in the lower courses of some of the glacial troughs we find unglaciated tributary valleys, with normal stream gradients. If the mouths of these tributaries are hanging above the main stream we can estimate, by the amount of the topographic unconformity and by the gradient of the tributary stream, the amount of glacial deepening which the main valley has undergone from glacial erosion. These estimates are subject to error for several reasons (see p. 12), and the results can be only approximate.

East of Copper Mountain and about 2 miles above the terminus of the Tenmile Creek system of glaciation the tributaries which join the Tenmile Valley from the east end about 400 feet above the main stream (fig. 12). By continuing the gradient of the tributary in a normal way to a point above the axis of the main valley we get a difference of about 200 feet, which appears to be approximately the

amount of glacial deepening at this point. The ice at this place had, however, descended almost to the 10,000-foot level, and its erosive

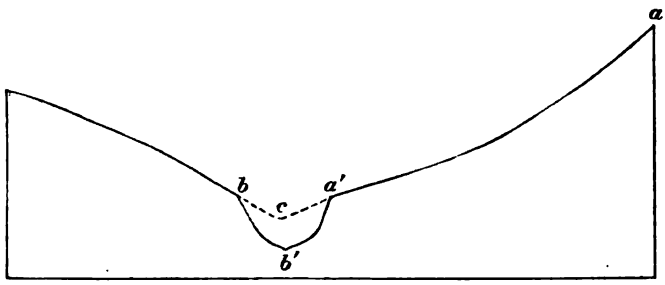


FIGURE 12.—East-west section across Tenmile Valley and an unglaciated, hanging tributary valley, *a*, *a'*. *a'*, *b*, *b'* is the glacially gouged valley. By the continuation of profile *a*, *a'* to *c* we get the approximate position of the preglacial valley axis. *c*, *b'* is the amount of the glacial deepening. Section is taken northeast of Copper Mountain. Horizontal and vertical scale, 1 inch = one-fourth mile.

power must have been less than it was farther up the valley, where the ice was thicker.

RECENT GRAVELS.

North of this system of glaciers, beyond the distal edge, there is a considerable body of recent gravels, deposited by Tenmile Creek as an alluvial fan of low slope. At this place Tenmile Creek and its West Fork emerge from their gorges, and this small park, with its lessened stream gradients, has been an area of stream deposition. The conditions of deposition during the last epoch of glaciation were very similar to the present conditions, and the recent alluvial deposits may be but the continuation of the gravel-train building processes of glacial times.

SYSTEM OF WEST FORK OF TENMILE CREEK.

Part of the valley of West Fork of Tenmile Creek was occupied by glaciers not connected with those in the main valley. This system consists of the glaciers in Jacque and Sugarloaf valleys, which joined to form a small ice tongue in the valley of West Fork.

Jacque Gulch is the eastern of the two tributaries of West Fork. It has two heads, one on either side of Jacque Ridge. The east head has steep head walls and the main valley was severely eroded by ice action. The ice at its maximum was not confined to the cirque itself, but extended up onto the flat west of Union Mountain and left the drift in which the three small lakes now occur. The head west of Jacque Ridge received most of its ice from Jacque Ridge. It is a long, narrow cirque, U-shaped in cross section, but its ice never had great depth.

The valley of Jacque Creek below these two heads is U-shaped, but the glacier it contained was never more than 200 feet thick. The sides of the valley are covered with heavy drift, but the stream has a shallow cut in the rock of the east valley wall. At the lower end of

Jacque Gulch some of the ice cut across the low end of the ridge to the east, as is shown by the bowlders over this ridge.

Sugarloaf Gulch held a very shallow ice body, though it sent its glacier down to the main valley. The supply of ice for this glacier came from Sugarloaf Ridge and from the névé field to the northwest, and it is doubtful if glaciation would have started in this valley if the exposure had been less favorable. The ice from Sugarloaf and Jacque creeks united in the main valley of West Fork of Tenmile, and sent their ice to a point 1 mile west of Wheeler. In this valley the ice reached only 100 feet up on the north valley wall, and left its drift in the form of a prominent bench running parallel with the stream. To the east this bench takes the form of a distinct moraine ridge, which becomes lower and lower downstream and finally merges into some new terrace remnants 15 to 20 feet above the stream.

WHEELER GULCH.

On the northwest slope of Copper Mountain there is an isolated glaciated valley which would have joined West Fork of Tenmile Glacier if its ice had reached down a little farther. This is in Wheeler Gulch. Its glaciated area is only 1½ miles long and one-third mile wide. In this area the ice was 100 feet deep at its maximum, so that its erosive action was slight. The gulch head is broad and shallow and the ice extended up to the col at its head. No definite areas of light and heavy drift could be defined, for the bed rock is nowhere bare, and talus and drift are commonly mingled. Between the forks of the stream there is a patch where the bowlders are numerous and predominate over the talus, but otherwise the loose material could not be characterized as heavy drift.

EAST SIDE OF PARK RANGE.

The lowest point in the valley of Blue River in this quadrangle is below 9,500 feet, and the small glaciers from the tributary valleys west of Breckenridge did not send their ice down to the main valley at this altitude. There were four of these small detached glaciers on the mountains west of Blue River.

SOURCES OF THE ICE.

Glacier 1 had two small heads, which joined in a broad U-shaped valley. The glacier was but little more than 2 miles long, its lower end being just beyond the edge of this quadrangle. The whole area is covered with heavy drift except the heads of the cirques, in which the walls and floor are masked by talus. On the northwest side of the valley there is a well-defined lateral moraine ridge 50 to 60 feet high. On the southeast the lateral moraine has no ridge-like crest, but is a broad belt of kettle-moraine topography, covered with bowlders.

Glacier 2, just southeast of glacier 1, was a feeble glacier about a mile long, and its erosion was slight. The whole area, except the head of the cirque, is covered with drift, which at one place is continuous with that of glacier 3. The topography of this area is that of a weak terminal moraine, but a distinctive terminal-moraine ridge is lacking.

Glacier 3 was a very vigorous little glacier, for it has a good cirque at its head, a well-developed U-shaped valley, strong lateral moraines, and an area of typical terminal moraine, yet the whole system is little more than 3 miles in length. The head of the cirque shows evidences of rather severe ice erosion, the west and northwest walls rising steeply to the limit of glaciation, and somewhat less steeply above it. On the southwest side the walls are not so high and the supply of ice was more limited, which accounts for the less severe erosion on this side. High up on the northwest side, just below the peak, there is a small hanging cirque in the mountain side, the ice from which evidently eroded its valley but little below the level to which the ice stood in the main valley. On the north side of the valley there is a fine lateral moraine, with a sharp, unbroken crest, extending from the mouth of the rock gorge to the point where the stream emerges from the glaciated area. This ridge, though not so high as the map indicates, is in places more than 200 feet above the valley, but rises only a little above the old drift against which it is banked on the outside. There is also a good lateral moraine on the southeast side of the valley, but this has not so high or so even a crest as its counterpart. It stands 150 feet above the stream and has an irregular surface, full of kettles and hummocks strewn with bowlders of granite and gneiss. The light-drift area of this valley includes only the rock walls of the gorge and the valley floor at the head of the cirque; otherwise the drift masks the rock in the whole of the glaciated area. At the lower end of the system is a small area of true terminal moraine piled up at the very edge of a patch of old drift. The relief of this terminal moraine is slight, with shallow lake-filled basins and low hillocks.

Glacier 4 was in what is now a small talus-filled valley which from above scarcely appears to be glaciated at all. Below, however, there is a definite terminal moraine which just touches the moraines of the Spruce Creek lobe. The whole of the lower end of the valley is covered with a thick coating of bowlder-strewn kettle moraine, which at the east forms two parallel crescentic ridges 20 to 30 feet high.

OLDER DRIFT.

Below the moraines of glaciers 1, 2, and 3 there are found patches of drift which both erosion and the condition of its material show to be distinctly older than the new moraines. In these patches are seen the same materials as in the new moraines, but in a more advanced state of decay and of oxidation. The surface, too, is under control by the streams, and no signs of kettles remain. This drift

has long since disappeared from the valleys and is now found only on the tops of the intervening ridges.

BLUE RIVER SYSTEM.

This system occupied the valley of Blue River from its head to a point one-half mile north of Breckenridge. It had a maximum length of 12 miles and an area of 14 square miles, and was formed by the ice from four cirques from the west joining in the valley of Blue River. No ice was contributed to this system from the east, probably because the mountains on that side are not so high as those on the west.

SOURCES OF THE ICE.

Spruce Gulch.—The northernmost of these tributary valleys is that of Spruce Creek, which has two distinct heads. The north head was very severely glaciated, the walls on the south side being particularly steep, so that the top of the ridge is in places reduced to ragged séracs. The rock is banded gneiss, and its weathering has developed

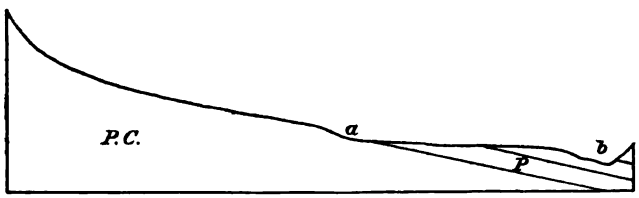


FIGURE 13.—Longitudinal profile of Spruce Gulch. *a*, Increased gradient of valley at point where stream flows from pre-Cambrian crystalline rocks (*P. C.*) onto lower Paleozoic beds (*P*). *b*, Valley of Blue River. Horizontal scale, 1 inch=1 mile. Vertical scale, 1 inch=one-half mile.

large heaps of talus at the base of the steep walls. On the north side there are few steep outcrops, the wall consisting of a more gentle, talus-covered slope. In the bottom of this head there is a beautiful little lake, the basin of which was made, in part at least, by talus from the slope above.

The south head of Spruce Creek is larger than the north head. Both walls are steep, and the valley bottom is free from large accumulations of drift. Even some rather large talus heaps fail to rob it of its "cleaned-out" appearance.

A noticeable feature of this cirque is the abrupt way in which the gradient of the valley floor increases just above the heavy-drift line, giving rise to cascades. There is a similar pitch in the valley floor of the north fork of Spruce Creek (Pl. V, *B*), and in Monte Cristo, Quandary, and Platte gulches. This pitch occurs in each case just above the contact of the sedimentary beds with the pre-Cambrian rocks, and is due to the lesser resistance of the sedimentary beds to glacial erosion (fig. 13). The heavy-drift area in Spruce Gulch extends up to the junction of the two cirques and reached a little way

A. CASCADES IN QUANDARY GULCH.

B. SPRUCE CREEK.

So filled with bowlders that the erosive action of the stream is almost blocked.

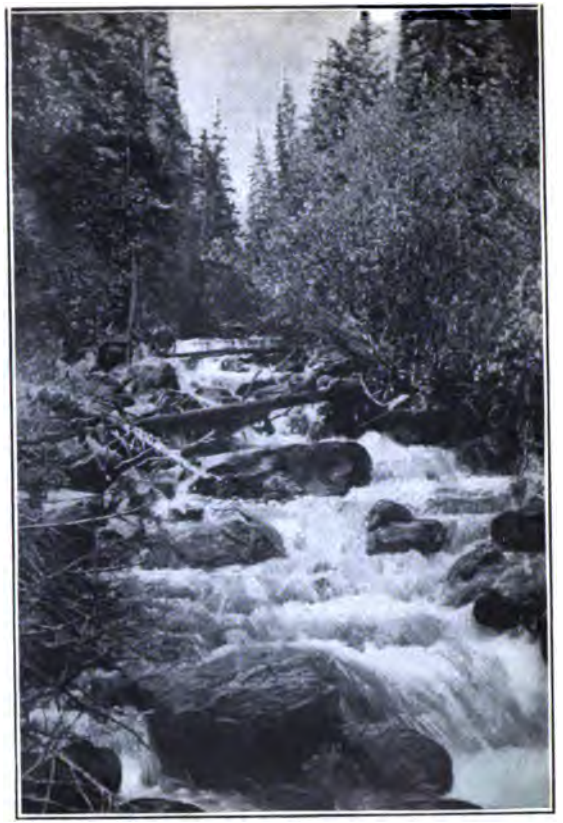
into them in the valley bottoms. On the north side of the valley the ice, emerging from the rock gorge above, stood too high to be confined by the lower valley wall and pushed over the ridge to the north, at an altitude of about 11,800 feet, and spread out in a broad, shallow lobe. Over this area there is now a thick deposit of drift lying in a series of parallel ridges with a relief of 20 to 50 feet, all running in a northeast-southwest direction. The surface is thickly strewn with bowlders 6 feet and less in diameter, and the topography is of the strong hillock-and-kettle type. This lobe extended to the north for almost a mile. On the south side of Spruce Creek the only lateral moraine is the ridge which was interlobate between the ice in Spruce Gulch and that in the Blue Valley. On the Spruce Creek side this ridge is only 25 to 50 feet high, but on the Blue River side it stands 200 and 300 above the stream. Spruce Creek is in places so blocked with bowlders that it is unable further to lower its bed (Pl. V, *B*).

Quandary Gulch.—The head of Quandary Valley is a beautiful cirque. The head and side walls are bare gneiss and rise very steeply, often terminating in a serrate crest. Above the limit of the heavy drift the valley is exceptionally free from loose materials, and with the exception of talus heaps at the base of the steep walls the bed rock is exposed over the whole valley. All these bare outcrops are smoothed and rounded, and from a distance the postglacial weathering is inconspicuous, but the rock has rarely preserved glacial striæ or polishing.

In the cirque the upper limit reached by the ice is easily seen, as there is a sharp contrast between the steep, smoothed slopes below and the more gentle slope above, with its rough outcrops and prevailing covering of talus. The rock is banded gneiss, and this determines the character of bowlders in the drift below. In the tributary valley on the north, a mile above the junction with the Blue River system, the glacial action was feeble and failed to deepen the valley to any considerable extent, and the rock is free from heavy drift on the head walls only. The lower end of this tributary hangs 300 feet above Quandary Creek. To the east of this draw the ice limit is about 400 feet above the stream. The upper limit is marked by a slight topographic bench with bowlders 10 feet and less in diameter. On the south side of the valley the ice reached to about the same height as on the north. The only approach to a lateral moraine is the occurrence in places of a bench-like deposit of drift high up on the valley wall.

Monte Cristo Gulch.—The east-west part of this valley is a type of a severely glaciated valley. Above the 11,000-foot level the bed rock, a banded gneiss, outcrops over the whole of the sides and floor of the valley. The valley has a beautiful U shape, the walls rising steeply to the upper limit of glaciation and somewhat less steeply

A. CASCADES IN QUANDARY GULCH.



B. SPRUCE CREEK.

So filled with bowlders that the erosive action of the stream is almost blocked.

above. Below the ice limit the bare rock is smoothed and rounded and the talus heaps, though numerous, are not large enough to spoil the perfect U shape of the valley. Above the ice limit the rock is almost completely covered by talus. Two beautiful lakes occur in the valley bottom, and the basin of the upper one is in rock. The lower lake is bordered by rock on one side, but below it there are talus heaps which may be responsible for its basin. At its upper end this cirque divides into two heads which curve back to the northwest. These heads become shallow toward their upper ends without decreasing much in width, so that at their heads the cross section is a much wider U shape. They are free from drift, and their walls were eaten back in places till they have jagged, serrate crests.

The little draw which fed its ice into the lower end of Monte Cristo Gulch from the south is only feebly glaciated and was little shaped by the ice. It has no cliff-like walls, and the whole area is covered with heavy drift. In the absence of drift the shape of this valley is not characteristic enough to show that it was glaciated.

Cirque south of Monte Cristo.—The southernmost tributary to the Blue Valley Glacier is a small cirque lying between Monte Cristo Gulch and Hoosier Pass. It is only a mile long and gave out an ice tongue of only moderate size. The head walls to the west are steep and cliff-like, but below these the ice did not profoundly alter the preglacial shape of the valley. Only the head of the cirque is free from a heavy-drift covering.

MAIN VALLEY AND ITS MORAINES.

The main valley of the Blue, from the Hoosier Pass road to the terminal moraine, is everywhere covered with heavy drift, except a part of the east valley wall. The trough has everywhere a broad U shape, and the river often meanders over the flat valley floor. The spurs from the rock ridges on both sides are truncated, and the unglaciated tributary valleys from the east are all hanging valleys. Above the mouth of Spruce Creek there is no good lateral moraine, and below Spruce Creek the lateral moraine stands up only a few feet above the old drift area against which it is built. The surface of this moraine shows a strong drift topography, and the new drift is apparently rather thick in many places.

The drift in this valley ends one-half mile south of Breckenridge, at which place the terminal moraine has a ridgelike front, rising abruptly above the fluviatile gravels below. The terminal-moraine area extends 2 miles upstream from the terminus of the glaciated area, and the topography is most irregular, as is characteristic of such deposits.

Beyond the terminal moraine the Blue Valley is filled with gravels, which are probably a result of the continued deposition since glacial times.

OLDER DRIFT.

West of the terminus of the Blue River system there is a long, narrow patch of older drift on the top of a ridge to the west of the new lateral moraine. Like the other patches of older drift, it is different from the new drift in being more weathered and in having lost its drift topography. The ridge form of this drift is not its original topography, but is the result of the cutting of the stream to the east and west, leaving the drift along the crest of the ridge.

SOUTH PLATTE SYSTEM.

The South Platte system of glaciers occupied the valley of South Platte River for 15 miles below the head of that stream, and had an area of 49 square miles. This is two and one-half times as large as the next largest system of the Park Range, that of East Fork of the Arkansas. All the ice came from the valleys of the Park Range, the lower mountains to the east being unglaciated. The area drained by these tributaries includes the east slope of the highest part of the range for 12 miles north and south, and the tributary valleys are correspondingly well developed and strongly glaciated.

SOURCES OF THE ICE.

Platte Gulch.—The head of this system and of South Platte River is the amphitheater at the head of Platte Gulch, a beautifully formed cirque. The floor of the upper part of the valley is for the most part devoid of loose material, and rounded outcrops of the bed rock, a banded gneiss, abound. There is very little talus in the head of this valley, and the surrounding walls were worn back till the divide is very narrow, hardly more than a line of serrate peaks. Most of the cirque is in the pre-Cambrian gneiss, but the tops of some of the surrounding peaks and ridges show the lower Paleozoic beds. In the north lobe of this valley the two little lakes are in rock basins. In the middle of July (1905) the upper one was still frozen over.

Just west of the bend in the Hoosier Pass road, above the point where the Paleozoic beds cross the valley, a spur of gneiss projects down into the valley from the north wall, constricting the valley and causing a steeper gradient around and below it. This seems to be correlated with the steep pitch of the valleys to the north, just above the contact of the igneous and the sedimentary rocks.

Lincoln Amphitheater.—In the east side of Mount Lincoln there is a small cirque called Lincoln Amphitheater. It is deeply eroded and its side and head walls are perpendicular in places, but great quantities of talus completely cover its lower walls and floor and fill it to such an extent as to alter considerably the shape of the cross section of the valley as left by the ice. The head of this cirque shows

utifully the contact between the pre-Cambrian rocks and the aleozoic.

Buckskin Cirque is a broadly U-shaped cirque divided into a umber of subheads by minor spurs which were themselves covered nd rounded off by the ice. The walls and floor of the head of the irque, especially on the east side, are so heavily masked by talus nat no evidence of glaciation, other than that of the general shape of e valley, remains; but on the west and north sides parts of the walls ave been cut back into steep cliffs.

In the lower end of the valley, at the point where the stream turns oward the east, the glacier emerged from its rock gorge and the teral moraines appear. On the north side of the valley the lateral oraine begins as a bench of drift on the side of the rock ridge. This bench is not always very definite, and as the side of the valley s heavily timbered it is difficult in some places to trace the upper dge of the drift, obscured as it is by talus and wash from above. One mile northwest of Alma the ridge is so low that the ice from the South Platte and from Buckskin Creek joined, and below this point the ridge is covered by a veneer of drift. On the south side of the valley the moraine ridge begins one-half mile northwest of Park City. Here the ice from Mosquito Gulch met that from Buckskin, and what from each valley appears to be a lateral moraine is in fact the interlobate moraine between the two. The crest of this ridge is broad and is strewn with bowlders up to 6 feet in diameter. The crest consists of a number of minor ridges from 8 to 20 feet high, running parallel with the two valleys. In the Buckskin Valley a mile above Alma is a thick deposit of drift just above the point where the ice from Buckskin met the southward-moving ice from the Platte, and this seems to be the terminal moraine of the Buckskin Glacier, when, during the retreat of the ice, it first became separated from the main glacier and became distinct. For one-half mile below this point there is little heavy drift in the valley of the Buckskin.

Mosquito cirques.—Mosquito Gulch has a fan-shaped head, and received ice from 4½ miles of the highest part of the Park Range. The head of the valley is divided by London Hill into two great heads, both strongly glaciated. The south cirque is wide, but the walls at the head are not very high and steep. The floor of the cirque rises, between London and Pennsylvania hills, toward the crest of the range in a series of huge, irregular steps, with no cliff at the head. This lack of steep cliffs may account for the comparative scarcity of postglacial talus in this valley. The bed rock of gneiss, everywhere rounded, shows throughout the valley floor.

On the northwest base of Pennsylvania Hill conditions are different. The wall is an almost perpendicular cliff to the top of the hill,

and is steep all the way down to the stream. Below this cliff there is a great talus heap, and on this wall the rounded glacial surfaces have disappeared.

London Hill stands between the two great heads of Mosquito Gulch. Once almost surrounded by the ice, its sides were smoothed off and steepened. On the west side of London Hill the ice from the two heads almost joined at the col, and moved downward on either side of the hill to join at its eastern end. Even above its glaciated flanks the hill is rounded, and the top is buried in the products of weathering.

The north head of Mosquito Gulch has much the same general characteristics as the south head. It is a broad cirque at the east base of London Hill, but becomes even broaded to the west. The wall to the northeast rises steeply and at the north a row of jagged peaks forms the dividing wall between this cirque and that at the head of East Fork of the Arkansas. The walls to the west, however, nowhere rise steeply, the valley having a nearly uniform gradient from the end of the railroad to the top of the ridge to the west. The bare rock, rounded and smoothed, is exposed over most of the valley floor, there being little talus. East of London Hill the ice from the two heads joined. The valley of the Mosquito below this point has a fine U shape. Heavy drift covers the valley bottom from London Hill to the terminal moraine, but the valley walls show the bare rock or talus slopes down to the point where the stream emerges from its rock canyon. One mile west of Park City a great granite spur runs down into the valley from the north. It shows evidences of severe glaciation, but was able to resist the erosion by the ice better than the other rocks on account of its superior hardness and freedom from fractures. Below the confines of the narrow gorge the ice flattened out and spread laterally until it met the ice from Buckskin Cirque, and with it formed a great interlobate ridge (p. 81). This bridge runs to the southeast for more than a mile, and then flattens out, as the ice from Mosquito Valley merged with the main Platte Glacier. In the lower end of the Mosquito Valley are several small lakes in depressions in the drift. On the south side of the Mosquito Valley the ice moved eastward along the flank of Pennsylvania Hill to a point almost due south of Alma, at which place it turned sharply to the south and joined the main Platte Glacier.

Sacramento and Little Sacramento gulches.—The ice from Sacramento Gulch was the southernmost tributary of the South Platte system. The ice came from the east slopes of Mounts Evans, Dyer, and Sherman and the Gemini Peaks, and the south slope of Pennsylvania Hill. This gulch has two heads, the smaller being called Little Sacramento Ampitheater. The main head is much the same in

character as the south head of Mosquito Gulch and is connected with it by a low col. Looking down from Pennsylvania Hill upon this col one can discern no sharp dividing line between the two cirques. The rock at the top of the col is smoothed and rounded, and the ice must have been thick over the col, reducing it to a low, rounded divide. With variations in the snowfall in the cirques on either side, the ice perhaps moved sometimes to the north and sometimes to the south over the crest of the col.

From the junction of Sacramento and Little Sacramento creeks the valley floor slopes upward with a rather uniform gradient to the col on the north and to the crest of the Mosquito Range on the west. There are no steep head walls, and the head of the valley is broad and shallow. In the absence of cliffs there is little talus, and the floor is of bare, rounded gneiss, with lakes in rock basins. South of Pennsylvania Hill the walls become cliff-like and there is much talus at their bases.

Little Sacramento Gulch is not so strongly glaciated as Sacramento Gulch, and like it has no steep walls. It contains considerable post-glacial talus and does not give the impression of very severe ice erosion.

The lateral moraine on the south side of the Sacramento Valley is an extraordinary one. It begins at the point where the ice emerged from the narrow gorge and extends eastward with an almost unbroken crest to South Platte River. At its upper end it is 400 feet above Sacramento Creek, but becomes lower to the east until it is less than 100 feet above the Platte at the point where that stream cuts through it. Over the surface bowlders of crystalline and lower Paleozoic rocks abound.

The lateral moraine on the north side of the valley is not so striking as that to the south. It begins somewhat farther east, and its crest is not so sharp and lacks the even, uninterrupted character of that of the south lateral moraine. The moraine material is scattered over the top of the ridge on the north side of the valley, the crest often showing a series of minor ridges 6 to 15 feet high, parallel with one another and with the stream. Rock outcrops beyond the ice limit show that the moraine is a drift deposit over a preexisting rock ridge, while the south lateral gives one the impression that it is composed entirely of the drift itself, irrespective of previous topography. No rock outcrops occur in the lower 4 miles of this moraine.

On the north side of the valley the ice covered the divide and showed a tendency to spread down into the next valley to the north. This probably accounts for the absence of a sharply defined lateral moraine ridge. Toward the lower end of the gulch the ice spread over the ridge to the northeast until it met the ice in the main valley of the Platte.

Between the lateral moraines the valley is broadly U-shaped. The stream meanders through a flat, except at the lower end of the valley, at the point where it enters the Platte Valley, at which place it has a cut 20 to 30 feet deep through the drift.

In the area mapped as covered with heavy drift there are occasional rock outcrops, but these are infrequent, and the drift in this area completely masks the topography of the underlying rock.

MAIN VALLEY AND ITS MORAINES.

In the main valley of the South Platte the upper end of the area of heavy drift below Hoosier Pass marks the division line between the area of accumulation and that of dissipation. Below this line the valley bottom is covered with heavy drift down to the lower end of the system. The east wall of the valley, however, is steep, and numerous outcrops of rock along it show that the drift is thin down

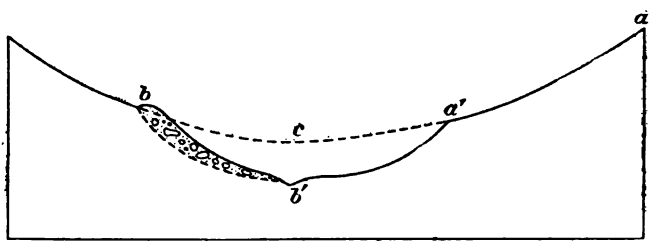


FIGURE 14.—East-west section of South Platte Valley between Mounts Lincoln and Silverheels. *a, a'*, Unglaciated tributary valley; *c, b'*, amount of glacial deepening of main valley. The west valley wall between *b* and *b'* is covered with drift. Horizontal scale, 1 inch=one-half mile. Vertical scale, 1 inch=one-fourth mile.

to a point within a mile of Alma. Above the limit of glaciation are a number of unglaciated hanging valleys which indicate the extent of glacial deepening this valley has suffered (fig. 14).

The west slope of the valley, above Alma, is covered with heavy drift up to the limit reached by the ice. The drift shows a low ridge form locally, but more often lies in a bench against the mountain slope. This drift has filled up the lower ends of the small draws which run into the main valley, and through this drift the streams have cut channels to depths of 50 feet and less.

Below Alma the drift on the east side of the valley becomes more prominent, and is disposed as a bench down to the 200-foot hill 1 mile southeast of London Junction. South of this hill a fine lateral-moraine ridge appears. At its upper end it rises 400 feet above the river, and its outer slope is 20 to 60 feet high. This moraine ridge continues southward, with a more or less regular crest, to the lower end of the system, where the Platte flows out of the glaciated area.

In the valley bottom, between Hoosier Pass and London Junction, there are patches of partially stratified drift which individually look

A. VIEW NORTH FROM POINT BEYOND END OF PLATTE SYSTEM OF GLACIATION.

The high terraces occupy the foreground, with the moraines of the last glaciers above. The ridge to the extreme right is covered with older drift.

B. SHALLOW DRAW BETWEEN TIMBERED NEW MORAINE CREST ON LEFT AND MATURE OLD DRIFT RIDGE ON THE RIGHT.

This locality is on the east side of Platte River, near the lower end of the Platte system of glaciation.

like terrace remnants. Taken collectively they have no definite relations between themselves, and cuts in them show the materials to be poorly or not at all stratified, so they seem to be merely phases of the heavy-drift deposit which covers the bottom of the entire north-south valley of the Platte within the glaciated area.

Little drift of distinctly terminal-moraine origin occurs in connection with this system. Across the Platte Valley there is a ridge of material which extends westward from the Platte and is continuous with the Sacramento south lateral moraine. This ridge is of drift, and shows some hummock-kettle topography on its north slope, but it can be considered as a continuation of the south lateral moraine of the Sacramento Glacier as well as the terminal moraine of the Platte system.

GLACIAL EROSION.

Besides the profound change in the cross section of the valleys of this system, which was due to glacial erosion, there was very considerable deepening of most of them by glacial scour and pluck. In the higher parts of the mountains, where every valley of considerable size contained a glacier, it is difficult to estimate the amount of this glacial deepening, but in the lower course of the glacier, where the tributary valleys were unglaciated, we have a basis from which to calculate the deepening. Such calculations are subject to error (see p. 12), but we can at least get an idea of the order of magnitude of this erosion. In the valley of the South Platte, 2 miles south-southeast of Hoosier Pass, a sketch made in the field shows the cross section to be as shown in figure 14. A tributary valley from the east ends 500 feet above the Platte, and a continuation of the stream profile would give a glacial deepening here of about 300 feet.

OLDER DRIFT.

At the lower end of the South Platte system there are two patches of older drift, lying just outside of the later moraines, one on the east side of the stream and one on the west (Pl. VI, *A* and *B*). The east patch covers the ridge between the Platte and Beaver Creek, and occupies the position the new moraine would have had if the ice had pushed a mile farther downstream. This drift is separated from the new moraine by a shallow draw, but is distinct from it in its surface configuration. The surface shows bowlders deeply decayed, with the more resistant crystals weathered into prominence. At the south end of this patch the drift forms a thin veneer over the red grits of the ridge, and the drift itself shows a strong red tinge, due to the grits which the ice has incorporated into the drift here.

The patch west of the Platte lies for the most part between the East Leadville road and the moraines of the last epoch. No cuts were

observed, but the bowlder-strewn surface has much the same appearance as the older drift has in other places. This patch shows that the older ice extended at least a mile farther south than the last ice.

During the summer of 1906 the excavations at the Snowstorm placer mine, in the moraines of the Platte system, southeast of London Junction, showed the fresh, unoxidized drift of the last ice epoch overlying a body of oxidized and decayed drift of notably greater age.

HIGH TERRACES.

Beyond the end of the moraines of this system there is an extensive deposit of gravels, which bears the same relations to the older drift deposits of this system as the high terraces in the Arkansas Valley bear to the older drift there. These gravels are very imperfectly stratified and slope away from the lower end of the Platte and Horseshoe Gulch systems of glaciation, with an angle of 3° to 3½° (Pl. VI, *A*), which decreases to 2° a few miles below these moraines. The gravels are deeply oxidized, and many of the pebbles are decayed and crumbling.

Platte River, unlike the Arkansas, has not been able to intrench itself deeply into these gravels, and they have not been reduced to terraces, so characteristic of similar gravels in the Arkansas Valley.

CLIFF GLACIERS ON MOUNTS LINCOLN AND BROSS.

Cameron Amphitheater.—On the east side of the Mounts Lincoln and Bross ridge there are two small glaciated valleys, in which the glaciers were never strong enough to push down to join the glacier in the valley of the Platte. Of these tributaries the northern one, called by Emmons "Cameron Amphitheater," received the ice from the sides of Mounts Lincoln and Bross. Despite the fact that these are the two highest peaks in the range, the glaciation in this valley was very feeble. The ice was probably never more than 100 feet thick in this gulch, and the shape of the valley was not profoundly altered. The maximum length of this glacier was less than 1½ miles, and the materials of the drift are angular and little worn.

The slight development of the ice at this point was doubtless due to the small collecting area. The deep cirques to the north, west, and southwest received most of the snow from the mountains.

Bross Amphitheater.—The southernmost of these two cirques is cut into the east side of Mount Bross. The cirque walls are composed of the sedimentary beds, but the bottom is in the pre-Cambrian rocks. The head walls rise cliff-like above the valley floor, and the cirque head, though small, is U-shaped. Only the upper end of the valley is free from a covering of drift. The lower part of the glaciated area is covered with glacial débris, which lies as a broad lobe on the

mountain flank. This drift shows a marked morainic topography, though of slight relief, and is thickly strewn with bowlders up to 6 feet in diameter. At its lower edge the drift from this glacier comes within a few hundred feet of the drift in the main valley, but the two ice bodies were never connected.

HORSESHOE GULCH GLACIER.

The Horseshoe Gulch Glacier occupied the valley of Fourmile Creek for 10 miles below the head of that valley, and had an area of about 11 square miles. Its head was double and the southernmost part was again subdivided.

The north head of this valley shows the result of vigorous ice erosion and contains little loose material. To the north and toward Mount Sherman the head walls are steep and the deepening of the valley by the ice was considerable. To the west the valley floor rises more gently toward the crest of the range, and the ice failed to excavate this side of its bed sufficiently to form steep cliffs at its border.

The north half of the south head is cut into the steeply dipping sedimentary beds, which impart to the cirque head the beautiful arched appearance that has given it the name "Horseshoe." At the Horseshoe the head and side walls are cliff-like and have large talus slopes at their base. The south division of this head is much like the one to the north, and gives the same arched appearance to the beds, though in a much less striking way. The head is less perfectly formed, and its symmetry is marred by quantities of postglacial talus.

Along the Sheep Mountain ridge the upper ice limit can be located rather sharply by the topographic break in the slope, the walls rising steeply to the upper limit of glaciation and less steeply above it. On the north side of the valley this upper limit is much less sharply defined. Below Sheep Mountain the walls are very steep and deeply weathered, so that the ice limit has become indistinct and the base of the cliff is buried deeply by talus. East of Sheep Mountain the ice emerged from its narrow gorge and spread out to form a great broad lobe flanked by strong lateral moraines.

On the northeast side of the valley the lateral moraine begins at the point where the ice emerged from its narrow canyon. It swings away from the rock ridge and runs to the southeast, with a fine, level-crested ridge. At its upper end this ridge is 400 feet above the stream, but becomes lower downstream. In many places the crest is composed of a number of minor ridges, 10 to 20 feet high, parallel with one another and with the main valley. Bowlders are scattered thickly over the surface of this moraine, and the ridge seems to be almost entirely composed of drift, as there are no rock outcrops east of East Leadville.

The southwest lateral moraine lies against the rock valley wall and is not so striking a topographic feature as the opposite ridge, although of about the same height. It lacks the fine ridge form of the northeast moraine and appears as a bench of drift on the rock valley wall.

The Horseshoe Glacier left no good terminal moraine. The lateral moraines become lower and swing in toward the stream, and the drift gradually thins out to the southeast.

TWELVEMILE CREEK GLACIER.

The Twelvemile Creek Glacier headed back to the crest of the Park Range and occupied a tract 7 miles long, with an area of 6 square miles. The glacier was peculiar in that the ice in its head moved directly east while in its rock gorge, but below turned to the south, almost at right angles to the axis of the cirque.

The head of the system is partially divided by minor spurs into three divisions. Of these the south division has a steep wall a few hundred feet high at the very head, and below this the floor slopes with a uniform but steep gradient to the east. The middle division has a higher head wall, and here the glacial erosion was more severe, so that the slope is steep at the head, while the gradient of the valley below is more gentle. In the north division the head wall is steep, but the steepness resulted from the resistant quartzite beds more than from glacial cutting, for the head as a whole gives the impression of only slight glacial deepening, and the profile of the stream was not greatly altered by the erosion of the ice.

At the point where the small streams join to form Twelvemile Creek the valley becomes narrow. Here the ice was never more than 300 feet deep, and the shape of the valley was not profoundly changed by the ice. The walls show perpendicular outcrops up to the upper limit of glaciation, but no smoothed or striated surfaces remain.

Heavy drift occupies the valley bottom well up into the north and middle heads, and below the bend of the creek the whole of the glaciated area is covered with drift, which shows the hummock-kettle topography of a typical terminal moraine. No ice came down from Sheep Park. East of the bend in Twelvemile Creek, at the point where the ice pushed across the valley of Sheep Park Creek, it built up a good moraine ridge and forced the creek over to the east.

The whole north-south portion of this system is deeply covered with heavy drift. No good lateral-moraine ridge appears along the valley wall to the west, but between Twelvemile and Sheep creeks there is a great mass of drift formed of parallel north-south ridges having a strong terminal-moraine topography. This deposit becomes thinner to the south and finally disappears.

SOUTH FORK OF SOUTH PLATTE GLACIER.

The valley of South Fork of South Platte River held a glacier for 4½ miles below Weston Pass. It was fed by two shallow tributary gulches from the west and by the head of the main valley, but in none of these areas of accumulation was the ice of great depth or the glaciation severe. The head of the cirque below Weston Pass is covered with talus. The steep southwest slope of Weston Peak is so fractured and broken up that the upper limit of glaciation can not be located exactly, although ice certainly moved down the valley from this head.

The two tributaries from the west are shallow, the ice erosion being insufficient to convert them into cirques. The ice from the southernmost of these was not more than 75 feet thick where it joined the main glacier.

For 2 miles below the pass there is a rock ridge on the northeast side of the road, running parallel with it. There is but little drift on this ridge, although it was covered by the ice. Southwest of this ridge the heavy-drift area runs well up toward the valley head. Below the junction of the tributary valleys the main valley floor is covered with heavy drift. On the southwest wall there is an area where rock outcrops show through the drift, and another on the northeast wall, but as a whole the main valley contains sufficient drift to mask the surface of the bed rock.

Below the fork of the stream the ice was only 300 feet thick, and became thinner to the southeast. This small glacier did not build strong lateral moraines, and an occasional bench of drift on the rock wall is all that now appears. On the southwest side of the valley, above the thin-drift area, the drift has some depth, and takes on a hummock-kettle topography, with bowlders up to 6 feet in diameter scattered over the surface. Toward the lower end of the system the ice limit along the valley sides gradually approaches the stream, and the glacier ended at the point where the stream enters its narrow V-shaped gorge. No terminal moraine occurs, for any terminal materials deposited in the narrow gorge would naturally have been carried away rapidly by the stream, perhaps as fast as they were dropped by the ice.

WESTON GULCH GLACIER.

The Weston Gulch Glacier had a maximum length of 5 miles and an area of 3¾ square miles. It was fed by ice from two heads, one from the north and one from the south. The north head is a broad, comparatively flat area in which the amount of ice was barely sufficient to start movement. The head is wide and the ice affected the shape of the valley but little. Only the head walls are free from a covering of talus and drift.

The south head was in a narrow valley to the west of the main head of Weston Creek. In this valley the ice, accumulating on the east slope of the mountain, was higher on the west wall than on the east, and the surface of the glacier here sloped both to the east and to the north. In pushing north to join the other glacier this lobe crossed the main valley of Weston Creek, as is shown by the distribution of bowlders and drift. The ice from this head was barely strong enough to join that in the east-west valley of Weston Creek. Below the junction of the two heads the gulch is U-shaped for some distance downstream. The ice here was never more than 300 feet deep at its maximum, and this depth decreased rapidly to the west. The upper limit to which the ice reached is almost everywhere indistinct and could be determined only approximately. At an altitude of about 10,000 feet a drift plug lies across the valley, marking the lower limit of the ice. This drift has no terminal-moraine topography, but this was not to be expected where the glacier ended in a narrow gorge. The floor of the east-west gulch is everywhere drift covered, and bowlders of quartzite and pink and gray granite are numerous. Between Granite and Weston gulches, on the lower slopes of the rock valley wall, there are gravels of apparently the same age as the high-terrace gravels, but they occur as a thin veneer over the surface of the rock.

Near the mouth of Little Union Gulch the terrace materials have been cemented by calcium carbonate into a rather firm conglomerate, but this is a local phenomenon. Some of the beds here are rather well stratified and suggest the former presence of local lakes.

SLUMPED AREA.

East of the river near Crystal Lake station there is an area where extensive slumping has taken place in the terrace materials, giving rise to a topography which resembles that of a terminal-moraine area. There are many small lakes, with irregular hummocks between. Toward the upper end of the slumped area the material has taken the form of parallel ridges, parallel to the face from which the material slipped. The slope from the source of the material to the lower edge of the slumped area, a distance of about 2 miles, is only 4°.

EMPIRE GULCH GLACIER.

TOPOGRAPHY.

The Empire Gulch Glacier occupied the valley of Empire Gulch above an elevation of about 10,000 feet. This glacier was a little less than 5 miles long and had an area of only 3 square miles, yet it was vigorous, and profoundly altered the valley in which it lay. It was fed by the ice from but one cirque head. This head is in the pre-Cambrian rocks, and the head walls rise to steep, angular peaks. The

A. TERMINAL MORAINE OF EMPIRE GULCH SYSTEM.

Lying in a gulch cut in the high terraces before the last glacial epoch.

B. UPPER EMPIRE GULCH, FROM LONG AND DERRY HILL.

rock, easily weathered, retains no striated or polished surfaces, but the broad U shape of the valley bears testimony to the severity of the ice action (Pl. VII, *B*). Only a moderate amount of talus occurs at the base of the clifflike head walls, and the bed rock, smoothed and rounded, outcrops over much of the cirque floor.

From the southwest flank of Long and Derry Hill a fine lateral-moraine ridge, 300 feet high at its head, swings down the valley side. West of Long and Derry Hill this ridge does not lie against the valley wall, but stands as a great ridge away from the rock ridge, 100 feet high on the outside and 200 feet on the inside.

The south lateral moraine is not very prominent. On the north flank of Empire Hill there is no drift, and the moraine takes on a low ridge form for only 1 mile above the terminal. West of the Union Gulch road the two lateral moraines converge rapidly, and join at about the 10,000-foot level to form a distinct terminal moraine (Pl. VII, *A*). In the terminal-moraine area the topography is most irregular and some of the larger kettles are occupied by lakes. The

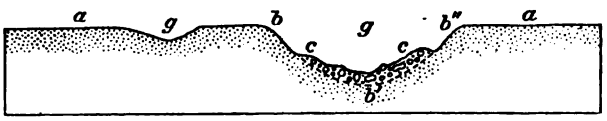


FIGURE 15.—Cross section across Empire Gulch one-half mile above lower end of Empire Gulch system. *a, a,* Plane of the high terraces, with plane of gulches (*g, g*) cut into it before the last ice epoch; *b, b', b'',* cross section of the gulch before last ice advance; *c, c,* moraine of last epoch. Horizontal and vertical scale, 1 inch=one-third mile.

terminal moraine lies in a postglacial cut in the high-terrace gravels, and the terrace level is well above the top of the moraine at this place (fig. 15).

OLDER DRIFT.

At only two places on the west slope of the Park Range was any evidence of older drift discovered. One of these occurs in connection with the Empire Gulch Glacier. Just south of the terminal moraine of the last glacial epoch, at the base of Empire Hill, there is a patch of somewhat weathered erratic bowlders, most of them composed of the pink granite found farther to the east, which lie about 100 yards south of the edge of the new drift and 30 to 50 feet above it, on the opposite side of a low rock ridge. These bowlders could not have been brought to their present position by streams, and were probably left by the ice of an earlier epoch, which rose higher in the valley than did the last ice. The bowlders are much weathered and are deeply embedded in the soil.

Estimates of the amount of glacial deepening in Empire Gulch were made, based upon the same assumptions as were the estimates made for the Tenmile Valley. (See p. 9.) Here the tributary

from the north side of Empire Hill ends 800 feet above the stream, which would indicate a glacial deepening of about 400 feet (fig. 16).

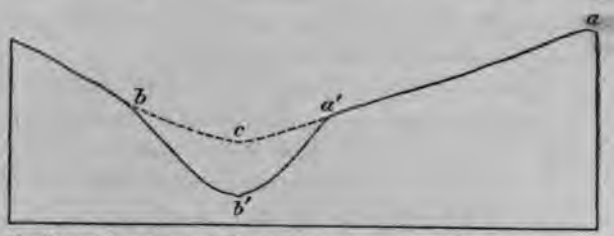


FIGURE 16.—North-south section of Empire Gulch south of Long and Derry Hill. *a*, *a'*, Ungiaciated tributary; *c*, *b'*, glacial deepening of Empire Gulch. Horizontal and vertical scale, 1 inch=one-half mile.

HIGH TERRACES.

In connection with this glacial system there is a great development of high-terrace gravels. These terraces originally formed a gravel plain, which extended on the east side of Arkansas River from Granite Gulch to a point 2 miles north of East Fork of the Arkansas. As these gravels were originally deposited as a compound alluvial fan by the streams flowing from Weston, Empire, Iowa, Evans, and East Fork gulches, it is impossible to limit the materials which came from any one of these streams. This whole terrace area will therefore be described under the next heading.

IOWA GULCH GLACIER.

TOPOGRAPHY.

Iowa Gulch contained a glacier more than 7 miles long, which extended down to an altitude of 9,850 feet. The head of this gulch is roughly divided into three cirques, which received the ice from the west slopes of Dyer Mountain, Mount Sheridan, and the Gemini Peaks. The head southwest of Dyer Mountain has its walls in the Paleozoic beds, but the valley bottom is in the pre-Cambrian rocks. The valley has a well-developed U shape, and the bottom is fairly free from talus, except at the base of the steep walls. The ice in this cirque extended almost to the col at the valley head.

The head southeast of Dyer Mountain is in the crystalline rocks and is deeply eroded, though not of a very broad U shape. The bed rock is exposed over much of the valley floor, but it is concealed by talus at the foot of the cliffs.

The south head is only a slight reentrant into the south valley wall. The entire south wall of the valley, above the lateral-moraine deposits, is composed of fractured and broken outcrops of rock above and of deep talus heaps below, so that the limit to which the ice reached could be determined only approximately.

The south lateral moraine begins about 3 miles above the terminus, and at its upper end takes on a ridge form above the high-terrace gravels which form the walls of the valley at this place (fig. 17).

On the north side of the valley the drift first appears as a covering of the rock wall, but becomes thicker to the west, and locally shows a ridge form. A little below the 10,000-foot level the laterals converge to form a terminal moraine, consisting of a large body of drift lying across the valley, which is here a cut into the high terraces. To avoid the highest part of this moraine the stream makes a bend to the south and flows around the obstruction. This drift has a strong, irregular topography, and at its highest point it stands about 100 feet above the stream to the south of it.

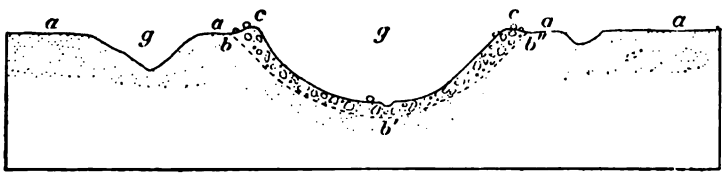


FIGURE 17.—Cross section across Iowa Gulch 4½ miles east of Arkansas River. *a, a,* Plane of high terraces, with gulches (*g*) cut into terraces after older ice epoch but before last ice epoch; *c, c,* moraines of last glacial epoch built within one of the gulches. The section from north to south is 1½ miles long. Horizontal scale, 1 inch=one-half mile. Vertical scale, 1 inch=one-quarter mile.

HIGH TERRACES.

The high terraces are seen at their best between Little Union Gulch and East Fork of the Arkansas, and are continuous along the Arkansas between these streams, although deeply cut into by a number of gulches. They are of the same order as those west of the river, and were doubtless once continuous with them, with the river at the axis of the two slopes.

Although a part of the terrace area has been reduced in height and there are gulches up to 600 feet deep in them, the flat-topped ridges between the gulches are part of the same plain, and were once continuous with one another (fig. 17).

It is impossible, with our present knowledge, to estimate the amount of detritus which was necessary to form these terraces. Gulches cut several hundred feet into the gravels fail to show rock, while shafts sunk in the Arkansas flat to depths of more than 100 feet do not reach the bottom of this material.

The materials here are much like those of the terraces already described. The gravels are coarsest near the mountains and become finer toward Arkansas River. In general the materials are oxidized and yellow, though some sections show a pinkish gray. Everywhere

the granite bowlders are decayed and falling to pieces, while the quartzites remain sound.

Interbedded with the gravels in places are lenses of clay and sand, and there are suggestions of stratification in the gravels, but nothing approaching the perfect stratification of lake deposits was observed in any of the numerous sections offered by prospect holes and other cuts, and continuous beds of fine lancinated clays are altogether lacking.

The surface of the terraces has a profile, drawn from the mountains to the Arkansas, which is concave upward, and varies in slope from 1½° to 2° at the lower edge of the plane to 3½° at the upper edge. The whole area seems to be a great compound alluvial fan, with its principal foci at the points where Empire and Iowa gulches emerge from their rock gorges, while the smaller gulches north and south of these added their quota to the general plain.

The terraces on the Leadville side of the river can not, like those on the west, be traced directly back to bodies of older drift, for no such bodies now exist on the east side. The only older drift found here consisted of a few scattered bowlders south of Empire Gulch, which were just above the upper edge of the terrace gravels. These deposits, however, are contemporaneous with the terraces west of the river, as is shown by the correspondence in the weathered condition of the materials, in the height of the terraces, and in their stage of dissection. As the terraces west of the river are directly traceable to older drift at their upper ends, those east of the river are doubtless the product of that same period of abundant waters and vast quantities of detrital materials.

LOW TERRACES.

In Iowa Gulch, below the moraines of the last glaciers, there are two small areas of low terrace gravels which rise 20 to 30 feet above

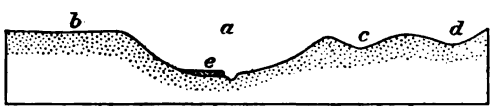


FIGURE 18.—Section across Iowa Gulch (*a*), showing high-terrace level (*b*), remnant of low terrace (*c*), and portion of high terrace reduced in height by development of contiguous gulches (*a*, *c*, and *d*). Horizontal scale, 1 inch=one-half mile. Vertical scale, 1 inch=one-fourth mile.

the flat of the gulch bottom (fig. 18). These terraces are 150 feet below the level of the high terraces, and are the remnants of a gravel train deposited during the last glacial epoch. In age and amount of erosion these gravels can be correlated with the latest moraines, but the waters of Iowa Creek, confined in the bottom of the narrow gulch, have in postglacial time removed all of the low-terrace gravels but these two patches.

A. LITTLE EVANS CIRQUE.

B. POSTGLACIAL CUT IN DRIFT AT MOUTH OF LITTLE EVANS GULCH.

EVANS GULCH SYSTEM.

Evans Gulch was occupied by a glacier from its head down to Leadville, a distance of 6½ miles. Two large cirques and one small one contributed ice to this glacier, which had a total area of 6½ square miles.

The head of this system took its ice from the slopes of Mount Evans and Dyer Mountain. This cirque is large and broadly U-shaped and is cut down into the pre-Cambrian gneiss. At its upper end the east wall of this valley rises in an almost perpendicular cliff below Dyer Mountain. Between Dyer Mountain and Mount Evans the divide shows serrate peaks where the Sacramento and Evans glaciers have worked their head walls back to the crest of the ridge. The lower and more gentle slopes of the cirque walls are deeply buried in talus.

For the upper 2 miles of its course Evans Creek flows to the northwest; then it turns sharply to the southwest. North of this bend there is a small valley running back to the north which was occupied by ice, but the erosion in it was never strong enough to excavate it into a cirque.

South Evans Gulch had an ice lobe of some size, but the ice here was never very deep or of very great erosive power. Some drift covers the lower valley floor, and the talus-covered slopes above the ice limit are in contrast with the steeper glaciated slopes below.

On the south side of Evans Gulch the heavy-drift deposits first become prominent one-half mile east of Yankee Hill. Here the south valley wall becomes lower and the ice spread out in a spatulate lobe, covering Fryer and Yankee hills and reaching south a little beyond Stray Horse Gulch. Over Fryer and Yankee hills it left drift of varying thickness, cuts in which show fresh drift and striated subangular bowlders. The west base of Fryer Hill marks the edge of the glaciated area, and the terrace gravels slope away below.

On the north side of Evans Gulch the lateral moraine is much more definite. From the spur on the east side of Little Evans Amphitheater the lateral moraine swings to the west with a high, distinct ridge. This ridge extends without a break across the mouth of Little Evans Amphitheater, its crest 400 feet above the valley floor, and continues westward as a distinct ridge for more than 3 miles. Toward its western end this ridge becomes lower and wider and takes on a hummock-kettle topography, showing a number of low ridges running parallel with the stream. On the north this moraine extends to the bottom of Little Evans Valley, which was formed by the building up of this ridge of drift at the foot of the rock slope. At one place near the lower end of Little Evans there is a postglacial cut 30 feet deep into the rock, where the moraines of the

glacier forced its extraglacial stream onto the slope of the rock valley wall.

Little Evans Amphitheater is cited by Emmons as a cirque cut by the ice of an earlier epoch of glaciation, because the Evans lateral moraine of the last epoch crosses the mouth of Little Evans Amphitheater without a break, and forced the drainage from Little Evans cirque to find a new outlet north of the Evans moraine. There is no doubt, however, that Little Evans cirque was occupied by a glacier of the last epoch (Pl. VIII, *A*). This glacier was not long enough to reach the ice in the main valley of Evans Creek, so the Evans Gulch Glacier built its lateral moraine without interruption across the Little Evans Valley, and the Little Evans Glacier pushed down to the edge of the Evans Gulch moraine and deposited its drift against the outside of this moraine. Little Evans Amphitheater itself is as fresh in appearance as any of the cirques of this neighborhood, and the drift at its mouth has the fresh, hummocky topography and uneroded surfaces of the last drift. The stream from the cirque has a shallow V-shaped cut in this drift (Pl. VIII, *B*), and the bowlders of the moraine are fresh and firm. The ice from this cirque barely failed to connect with the Evans Glacier.

INDEX.

A. Page.

Alma, glaciation near..... 84
Arkansas, Mount, glaciation on..... 66
Arkansas River, course of..... 8
drainage of, changes in..... 24–25
flats on..... 23
section of, description of..... 15
figure showing..... 15
terraces on..... 15–17
See also Terraces.
valley of, glaciers in..... 18–19
Arkansas River (East Fork), glacial system of..... 65–69
glacial system of, erosion of..... 69
moraines of..... 68–69
section of, figures showing..... 68
view of..... 68
sources of..... 65–67
terraces of..... 69
main valley of, glaciation in..... 67–68
section near, figure showing..... 67

B.

Barlett Mountain, cirque near..... 70
Birdseye Gulch, glaciation in..... 65
Blue River, drainage of..... 8
glacial system of..... 77–80
drift of..... 80
moraines of..... 79
sources of..... 77–79
glaciers near..... 75–76
main valley of..... 79
Bowlders, plates showing..... 40, 78
Breckenridge, glaciation near..... 77
Bross, Mount, amphitheater in..... 86–87
Buckeye Gulch, cirque in..... 65
Buckeye Peak, cirques near..... 66
Buckskin, Mount, cirque near..... 66
Buckskin Cirque, description of..... 81
Busk, drift near, view of..... 40

C.

Cache Creek, map showing..... 63
Cameron Amphitheater, glaciation of..... 86
Chalk Mountain, erosion on..... 67
glaciation on..... 66
Cirques, development of..... 10–11
See also particular places.
Clear Creek, glacial system of..... 64–65
Cliff glaciers, occurrence and character of..... 45, 54, 86–87
Clinton Gulch, cirque in, view of..... 68
glaciation of..... 70–71
view of..... 68

Page.

Copper Creek, glaciation on..... 72
Copper Mountain, glaciation on and near..... 73, 75
Crane Park, glacial system of..... 38–40
glacial system of, drift of..... 23, 40
sources of..... 38–40
Crane Park Glacier, flat formed by..... 23, 40
Crystal Lake, glaciation near..... 90
view near..... 56
Crystal Lake Gulch, cirque in..... 56
description of..... 60
sections of, figures showing..... 61

D.

Derry Hill, moraine on..... 91
Drainage, changes in..... 23–25
Drift, older, occurrence and character of..... 14
See also particular places
Dyer Mountain, ice from..... 95

E.

Eagle River, course of..... 8
drainage of, change in..... 23–24
map showing..... 23
flat on..... 22–23
Echo Gulch, cirque in..... 55
Elbert, Mount, ice from..... 54
Elbert Creek, glacier on..... 50
Emmons, S. F., on Arkansas River changes. 24–25
on terrace deposits..... 19
Empire Gulch, glaciation in..... 90–92
glaciation in, drift in..... 91–92
erosion in..... 12
terraces of..... 92
view of..... 90
valley of, sections of, figures showing..... 91, 92
views of..... 90
Empire Hill, moraine on..... 91–92
Erosion, postglacial, amount of..... 25
See also Glacial erosion.
Evans, Mount, ice from..... 92, 95
Evans Gulch, glaciation in..... 95–96
Evergreen Lakes, description of..... 48
glacial system of..... 45–48
drift area of..... 47–48
moraine of..... 48
sources of..... 45–47

F.

Flats, occurrence and character of..... 22–23
Fremont Pass, glaciation at..... 67
Fryer Hill, drift on..... 95

G.

Page.
Geologic map of quadrangle..... Pocket.
Glacial erosion, features of..... 10-12
methods of..... 12
See also Cirques; *particular places, etc.*
Glacial streams, terraces formed by..... 18
Glaciation, area subjected to..... 8-9
effects of, figures showing..... 59,60,61
elevation necesssary for..... 9-10
epochs of..... 14-15
evidences of..... 8
periods of..... 20
See also Interglacial epoch; Glacial erosion; *particular places, etc.*
Glaciers, elevations of..... 9
location of..... 9
size of, controlling factors of..... 10
Gold Park, glaciation at and near..... 32-36
Gorges, interglacial, cutting of..... 20-21
Granite, section near, figure showing..... 15
terrace near..... 65
Granite Gulch, glaciation near..... 90
Ground moraines, description of..... 13-14

H.

Half Moon Creek, glacial system near..... 48-49
glacial system of..... 49-53
drift area of..... 51-52
moraines of..... 51
sources of..... 49
terraces of..... 52-53
main valley of, glaciation in..... 50-51
Hayden, F. V., on glaciation of Arkansas River..... 10
Hayden Gulch, cirque in..... 55
Hill, J. M., work of..... 7
Holy Cross Mountain, cirque near..... 26
Homestake Creek, glacial system of..... 28-36
glacial system of, deposits of..... 22-23, 32-34
sources of..... 28-32
main valley of, glaciation in..... 34-36
section of, figure showing..... 35
Homestake Creek Glacier, flat formed by ... 22-23, 32-34
Homestake Peak, cirque near..... 38
Homestake Valley, erosion of, depth of..... 12
Hoosier Pass, moraine at..... 84
Horseshoe Gulch Glacier, description of..... 87-88
Humbug Gulch, glaciation in..... 71-72

I.

Interglacial epoch, occurrence of..... 20
Iowa Gulch, description of..... 92-93
erosion in, depth of..... 17
glaciation in..... 92-94
terraces of..... 93-94
section in, figure showing..... 94

J.

Jacque Gulch, glaciation of..... 74-75

K.

Kirtley, C. A., work of..... 7

L.

Page.
Lake beds, description of..... 19
Lake Creek, glacial system of..... 54-63
glacial system of, drift area of..... 57-58, 61-62
erosion of..... 12, 59-61
figures showing..... 60, 61
section of, figures showing..... 60, 61
sources of..... 54-57
terraces of..... 62-63
gorge of, plate showing..... 56
main valley of, glaciation in..... 57
map showing..... 63
rocks in, view of..... 56
Lake Fork, glacial system of..... 40-45
glacial system of, drift area of..... 41-42
view of..... 40
moraines of..... 42-44
sources of..... 40-41
terraces of..... 44-45
valley of, decayed bed rock in..... 41
decayed bed rock in, view of..... 40
Lakes, terraces formed by, theory of..... 18-19
La Plata Basin, cirque in..... 55-56
La Plata Gulch, glaciation of..... 55
Lateral moraines, description of..... 13
Leffingwell, E. D. K., work of..... 7
Lincoln, Mount, glaciers on..... 86
Lincoln Amphitheater, glaciation of..... 80-81
Little Evans Amphitheater, glaciation in.... 95-96
view of..... 94
Little Sacramento Amphitheater, glaciation in..... 82-84
Little Union Gulch, glaciation in..... 90
Little Willis Gulch, glaciation of..... 56-57
London Hill, cirques near..... 81-82
London Junction, glaciation near..... 84
Long and Derry Hill, moraine on..... 91

M.

Map, geologic, of quadrangle..... Pocket.
Massive, Mount, cirque near..... 49
Mayflower Gulch, glaciation in..... 71
Mesas, occurrence of..... 16
Mitchell, glacier east of..... 38
moraine near..... 40
Mitchell glacial system, description of..... 36-37
Monitor Gulch, cirque in..... 55
Monitor Rock, location and character of..... 57
view of..... 56
Monte Cristo Gulch, cirque near..... 79
glaciation in..... 78-79
Moraines, description of..... 12-14
Mosquito Gulch, cirques in..... 81-82
section near, figure showing..... 67

P.

Pando, flat near..... 22-23
Park Range, glaciation on..... 10, 75-76
location of..... 8
terraces on..... 17-18
Pennsylvania Hill, cirque near..... 81-82
Platte Gulch, cirque in..... 80
Plucking, description of..... 12
Prospect Mountain, cirque on..... 65

Q.

Page.

Quandary Gulch, cascades in, view of..... 78
glaciation in..... 78

R.

Rasping, description of..... 12
Robinson, moraine near..... 70
Roche Moutonnée Creek, glacial system on.. 26-27
Roches moutonnées, occurrence of..... 26
Rock decay, plate showing..... 40
Rock Creek, glacial system of..... 27-28

S.

Sacramento Gulch, glaciation in..... 82-84
Salisbury, R. D., aid of..... 7
Sawatch Range, glaciation on, elevation of.. 9-10
location of..... 8
Sheep Mountain, glaciation on..... 87
Sheep Park Creek, moraine on..... 88
Soda Springs, glacier near..... 45
South Platte Glacier (South Fork), description of..... 89
South Platte River, drainage of..... 8
glacial system of..... 80-86
drift of..... 85
erosion of..... 85
sources of..... 80-84
terraces of..... 86
main valley of, erosion of..... 12, 85
glaciation in..... 84-85
section of, figure showing..... 84
terraces in, views of..... 84
Spruce Gulch, channel of, view of..... 78
glaciation in..... 77-78
section of, figure showing..... 77
Striæ, description of..... 14
Sugarloaf Gulch, glaciation in..... 75

T.

Tenmile Creek, course of..... 8
glacial systems of..... 70-74
drift areas of..... 70, 72-73

Page.

Tenmile Creek, glacial systems of, erosion of. 73-74
glacial systems of, gravels of..... 74
sources of..... 70-72
valley of, glaciation in..... 73-74
section of, figure showing..... 74
Tenmile Creek (West Fork), glacial system of. 74-75
Terminal moraines, description of..... 13
Terraces, high, age of..... 17-18
material of..... 16
occurrence and character of..... 15-17
origin of..... 18-20
view of..... 16
Terraces, low, occurrence and character of... 21-22
Topography, description of..... 8
Tucker Gulch, glaciation in..... 72
Twelvemile Creek Glacier, description of.... 88
Twin Lakes, glacial system of. *See* Lake Creek.
moraine of..... 62-63
origin of..... 58

V.

Valleys, glacial erosion of..... 11-12, 59-60
glacial erosion of, figures showing..... 59, 60, 61

W.

Westgate, L. G., on Arkansas Valley changes. 24
on glacial erosion..... 59
Weston Creek, glaciation in..... 90
Weston Gulch Glacier, description of..... 89-90
Weston Pass, glacier near..... 89
Wheeler, glacier near..... 70
Wheeler Gulch, glaciation in..... 75
Whitney Peak, cirques near..... 28, 32
Willis Gulch, glaciation of..... 56
view near..... 56

Y.

Yankee Hill, drift on..... 95

Z.

Zion, Mount, moraine on..... 68

-44
-41
45

79
9

BRANNER EARTH SCIENCES LIBRARY

Stanford University Libraries
3 6105 019 731 731

550.6
U58
no.382-386

DATE DUE

STANFORD UNIVERSITY LIBRARIES
STANFORD, CALIFORNIA 94305-6004